HUMULTS OF WINDWARD OAHU, HAWAII, AND THE POTENTIAL RATINGS OF THESE SOILS FOR SELECTED USES

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ABSTRACT

An investigation of the Humults (Ultisols) of Windward Oahu, Hawaii, was made with the objective of determining and classifying the soil and landscape parameters for selected agricultural and nonagricultural uses, characterizing and verifying the classification of the soils of the study area, showing the geomorphic relationships of the Ultisols with other soils, proposing the potential rating of the soils for the production of banana and sweet potato and for dwellings and for construction of local roads or streets, and identifying the areas of further research required for efficient interpretation of soil and landscape data for different uses.

The soil order Ultisols dominate the sloping eroded landscape of Windward Oahu. Most of these soils are highly leached, contain appreciable amounts of extractable aluminum, and fix large amounts of phosphorus which can affect plant growth. Because of the appreciable amounts of organic carbon in the upper portion of the Bt or argillic horizon, these soils are further classified in the suborder Humults. The four important soil series, covering slightly over 10,000 hectares, are the Waikane, Lolekaa, Alaeloa, and Paumalu soils. They occur in areas with an annual rainfall ranging from 900 to 2,300 mm and with an isohyperthermic temperature regime.

Pedons or profiles of these Humults were collected and

laboratory data were obtained to determine the range in the characteristics of the chemical, physical, and mineralogical properties. These soils are very strongly acidic to strongly acid, with the pH values ranging from 4.5 to 5.4. The cation exchange capacity ranges from 13 to 25 meq/100 g of soil, while the base saturation of the surface horizon ranges from 22 to 45 percent. The base saturation decreases with depth. Because the subsoils have high amounts of extractable aluminum (as much as 12 meq/100 g) and consequently high aluminum saturation (as much as 88 percent), crop production on these soils is limited to plants that can tolerate appreciable amounts of soil aluminum or crop production can be maintained only with proper management. Banana and sweet potato are two crops which can tolerate such a condition.

Chemical, physical, and mineralogical properties were determined to verify the classification of the Humults. The laboratory data suggest a need to study further the Humults of Windward Oahu. It is likely that some of the Humults may need to be reclassified at the lower categories. In general, the Humults of Windward Oahu are Tropohumults with some of them tending to have properties of Palehumults. They all are of clayey family, generally with varying mineralogy.

The Humults of Windward Oahu occur on a sloping landscape and in association with Inceptisols, Entisols, Mollisols, and Vertisols. Association with Oxisols are of limited extent. Exposure of Windward Oahu to the Northeast Tradewinds and the subsequent effects of erosion is attributed to the occurrence of the existing landscape and soil associations and distribution.

A system of determining the soil potentials of the Humults of Windward Oahu for selected agricultural and nonagricultural uses was proposed. Potential ratings for the production of banana and sweet potato were used to illustrate the system for agricultural uses and ratings for dwellings and for the construction of local roads or streets were used to illustrate the system for nonagricultural uses. Certain soil and landscape parameters which cannot be altered easily by man (noncontrollable parameters) have strong influence or weightings than other parameters which can be altered by man (controllable parameters). Various criteria pertinent to the specific uses were rated and evaluated. The results of the ratings suggest that much of the Humults, especially those with steeper slopes, have poor or fair ratings for the production of banana and sweet potato in Windward Oahu. Humults with less steep slopes, however, have better ratings. The latter soils are limited in extent. The predominance of Humults with poor and fair ratings are to be expected because these soils are by definition highly leached soils with low inherent fertility and occur on sloping landscapes. The value of the potential rating system appears to be then in deciding which areas of Humults should be considered as "first" choice for a specific use.

Similar results of the ratings for dwellings and local roads or streets suggest that Humults in areas of steeper slopes have poor or fair ratings while those of less steep slopes have better ratings. These findings suggest further that in general soils that are good or fair for banana and sweet potato are also good or fair for dwellings and local roads or streets.

Although the final decision to use a particular site for a specific use will depend on other factors, such as socio-economic conditions, the concept of soil potentials can be used as an initial step in guiding the land users, land planners, and others in evaluating a soil, a parcel of land, or an area for a specific use.

Areas of further research include the systematic compilation of yield data of specific crops and refinement of the soil potentials approach. There is also a need to display the potential ratings for selected uses especially by means of a computerized display system. Several systems are in existence but they should easily be accessible and up-dated and be subject to modification so that the information may be useful not only for general planning, but also for specific planning.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

INTRODUCTION

Soils classified as Ultisols, more specifically the Humults (Foote et al., 1972), dominate the sloping landscape of Windward Oahu, Hawaii. At present much of this area is in small farms, pasture, scattered homes, or is simply undeveloped. As urbanization and other nonagricultural uses occupy the more level lands, there is a tendency to seek areas of Humults for these uses. There is, therefore, a need to investigate these soils and to suggest their suitability for various uses.

According to the Soil Survey Staff (1973), Ultisols are strongly weathered mineral soils, usually moist, with an argillic horizon consisting of translocated clays. At least during some seasons of the year, precipitation exceeds evapotranspiration and bases removed by leaching exceed or equal the amount released by weathering. In temperate areas, Ultisols are formed under forest vegetation in climates with slight to pronounced moisture deficits and surpluses. Ultisols are strongly acidic and show the ultimate effects of leaching. Base saturation by the sum of cations is less than 35% at a depth of 1.8 m below the surface of the soil or 1.25 m below the upper boundary of the argillic horizon, whichever is deeper. Extractable Al is usually high in these soils. Ultisols are inherently poor in soil fertility but have desirable physical properties and become productive when managed properly.

In Hawaii, Ultisols occur on the islands of Kauai, Maui, and Oahu. They occupy an area of approximately 40,000 hectares and rank fifth of the ten soil orders. On the island of Oahu, Oxisols are the dominant soils covering 20% of the land area, followed by Ultisols, which occupy 11% of the area. Oxisols are the extremely weathered soils of the tropics and occur on fairly stable landforms. Often, Ultisols occur in association with Oxisols, the former occupying the steep slopes. More than half of the Ultisols in Hawaii are found in Windward Oahu.

When classifying the Ultisols, the moisture regime and organic matter content are considered at the suborder level. The suborder Humults are Ultisols that are not associated with wetness and contain 0.9% of organic carbon or 1.5% of organic matter in the upper 15 cm of the argillic horizon and/or 20 kg of organic matter in a unit volume of one square meter to a depth of one meter exclusive of any 0 horizon. Humults occur in the high rainfall areas of the subtropical and tropical regions.

The soil survey of the islands of Kauai, Oahu, Maui, Molokai, and Lanai has been published by the Soil Conservation Service, USDA, in cooperation with the University of Hawaii Agricultural Experiment Station (Foote et al., 1972). Soil series descriptions, laboratory data of selected soils, classification, and land capability groupings for different uses are discussed in that report. When laboratory data are not available, inferences are made based on closely related soils. Soils with similar classification are expected to have similar properties. Thus, the properties of the Humults of Windward Oahu should be similar to those of the Humults of Leeward Oahu.

The efficient use of Windward Oahu Humults requires the knowledge of the important properties and behavior of these soils. These properties and behavior are in turn influenced by other factors. For example, the occurrence of post-erosional volcanoes in the Kaneohe-Kailua-Waimanalo area with accompanying or subsequent hydrothermal activities could result in different kinds of soil parent material when compared to those of the leeward side of the Koolau Range. Hence, efficient use of the Humults of Windward Oahu requires detailed investigation of their properties and behavior, the landscape, and the rating of the soils for different uses. The present study is conducted with the following objectives. They are:

1. To determine and classify the soil and landscape parameters for selected agricultural and nonagricultural uses.

2. To investigate and classify the soils according to the U. S. Soil Taxonomy.

3. To show the geomorphic relationships of the Humults with other soils.

4. To propose the rating of the soils for selected

agricultural and nonagricultural uses.

5. To identify the areas of further research required for efficient interpretation of soil and landscape data for different uses.

STUDY AREA AND SOIL FORMING FACTORS

Soil formation is the result of the interaction of climate, vegetation, topography, parent material and time (Jenny, 1941). Variation in one or more of the soil forming factors has resulted in different soils in a narrow strip of land in Windward Oahu. Along with the dominant properties of the soils, climate and topography influence the use of these soils. The influencing factors are discussed in the following sections.

The Humults of Windward Oahu occur on the narrow strip of land between the Koolau Range and the ocean extending from Kahuku to Waimanalo (Fig. 1). This Range is 59 km long and deeply dissected by numerous drainage ways. The width of the area of interest varies from less than a km to more than 10 km at the widest point.

Physiography

The windward side of the Koolau Range is severely eroded, exposing numerous vertical cliffs and amphitheater-headed valleys. The area has gently sloping valley floors of alluvial and colluvial materials. Deeply dissected uplands of the northern Koolau are less severely eroded with some ridge crests reflecting the former slopes. Coalescence of series of amphitheater-headed valleys has resulted in the formation of Pali. The severe

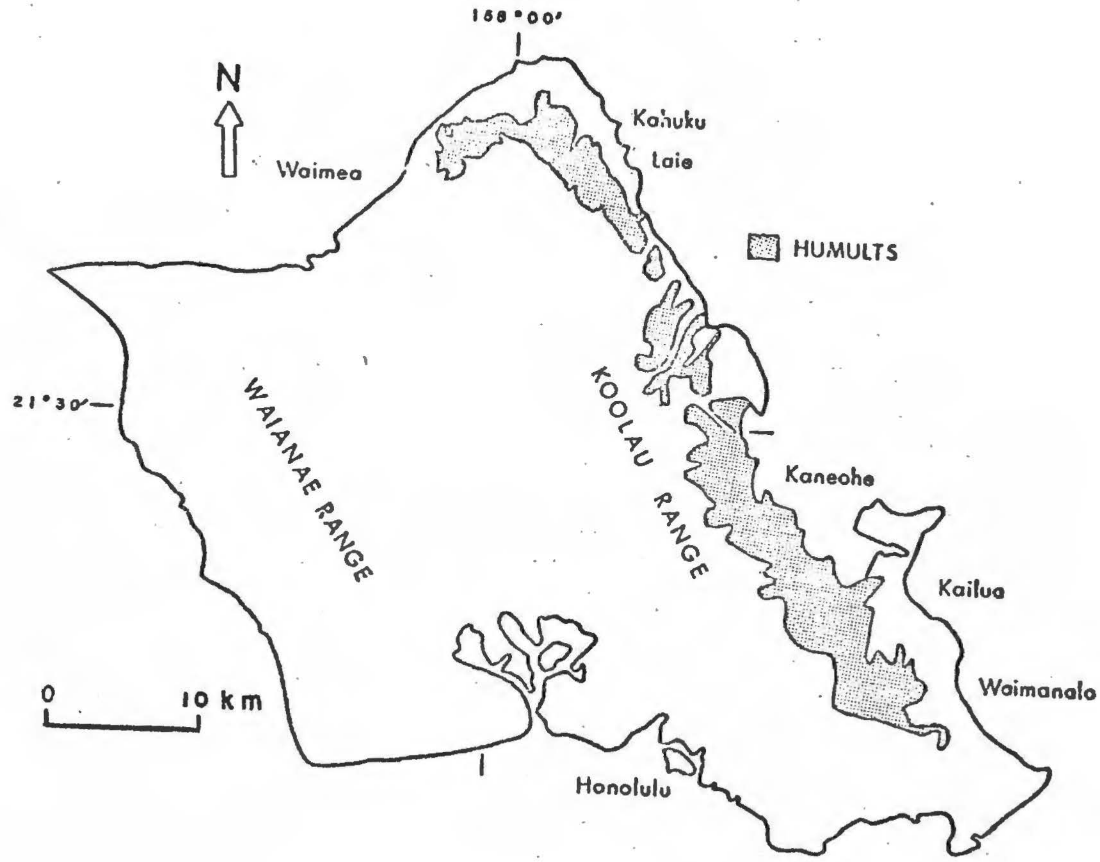


Figure 1. Areas of Humults in Windward Oahu.

erosion of Windward Oahu may be attributed to the direct exposure of the tradewinds, waves and high rainfall (Macdonald and Abbott, 1970). Some of the prominent valleys are Kahana, Kahaluu, Waiahole, Kaneohe, and Waimanalo.

Geology

Oahu is made up of the Waianae Range in the west and the younger Koolau Range on the east. The Koolau shield consists of thin narrow basaltic lava flows piled one upon another like shingles intermingled with ash and dikes (Stearns, 1966). These ranges are shield volcanoes that have been subjected to the effect of erosion. The crest of the Koolau volcano is centered near the foot of Nuuanu Pali and once stood 1800 m above sea level in a zone of maximum rainfall. Today, shoreline of the island of Oahu is approximately 360 m below the former sea level, and erosion is responsible for the present land forms (Macdonald and Abbott, 1970).

During the late stage of formation, the summit area of the Koolau shield collapsed to form a caldera. The boundaries of the caldera extend from near Waimanalo on the southeast to beyond Kaneohe on the northwest. The southern boundary lies close to the base of the Nuuanu Pali and the eastern boundary lies offshore. The caldera was gradually filled with lava flows to a level above the present height of Olomana Peak. The rocks in the caldera were subjected to volcanic gases and steam resulting in the alteration of primary minerals. Subsequent erosion of the area gave rise to the present landform.

The rocks of the Koolau Volcanic Series are tholeiitic basalts which are rich in Si, Mg, and Fe but low in Na and K. These rocks are primarily composed of plagioclase feldspar, pyroxene, and olivine in varying amounts. Hydrothermal activity in the Koolau caldera has altered the pyroxene primarily to chlorite and various oxides of Si, e.g., chalcedony, quartz, and opal. Olivine on the other hand, has been altered to serpentine and talc (Macdonald and Abbott, 1970).

On the southeastern end of the Koolau Range, more than 30 subsequent volcanic eruptions formed cinder, spatter, and ash cones and poured lavas over deeply eroded areas. Information on the secondary eruptions of the Honolulu Volcanic Series is presented in Table 1. The locations of the eruption sites are shown in Figure 2. Lavas of this Honolulu series are in general rich in Mg and Fe but poor in Si. The rocks include alkali basalts, basanites, and nephelinites (Macdonald and Abbott, 1970).

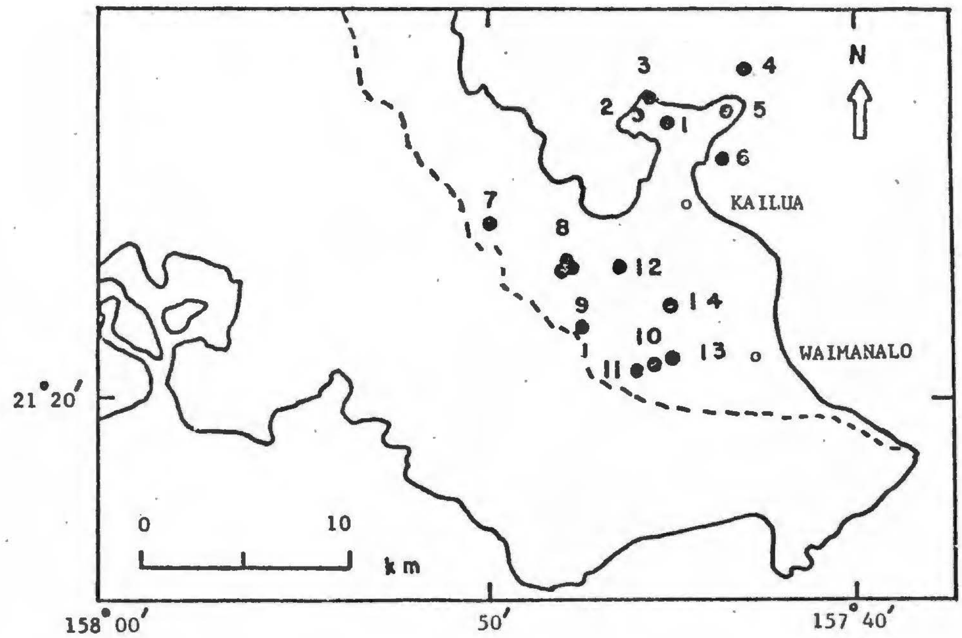
Climate

Orographic effects greatly influence the rainfall distribution, cloudiness, temperature and in turn soil development in the Hawaiian Archipelago. Hawaii enjoys a nearly uniform annual

Table 1. Secondary Eruption Sites of the Honolulu Volcanic Series on Windward Side of Koolau Range[1]

No.	Name	Sites	Materials Erupted
1	Hawaii Loa	Mokapu Peninsula	Cinders and lava
2	Pali Kilo	Mokapu Peninsula	Lava
3	Pyramid Rock	Mokapu Peninsula	Lava
4	Moku Manu	Islands off Mokapu Peninsula	Ash
5	Ulupau	Mokapu Peninsula	Ash
6	Mokulea	Kailua Bay	Lava
7	Haiku	Head of Haiku Valley	Lava and ash
8	Kaneohe	3.2 km south of Kaneohe	Cinders and lava
9	Pali	Pali Road	Cinders and lava
10	Makawao	3.2 km southwest of Olomana Peak	Ash, cinders and lava
11	Ainoni	3.2 km southwest of Olomana Peak	Cinders and lava
12	Castle	4.8 km east of Kailua	Cinders and lava
13	Maunawili	South side of Olomana Peak	Cinders and lava
14	Training School	North side of Olomana Peak	Cinders and lava

[1]Source: Stearns (1966).



1. HAWAII LOA
2. PALI KILO
3. PYRAMID ROCK
4. MOKU MANU
5. ULUPAU
6. MOKULEA
7. HAIKU
8. KANEOHE
9. PALI
10. MAKAWAO
11. AINONI
12. CASTLE
13. MAUNAWILI
14. TRAINING SCHOOL

Figure 2. Portion of the map of Southeastern Oahu, showing the distribution of vents of the Honolulu Volcanic Series in Windward Oahu. (<u>After</u> Macdonald and Abbott, 1970.)

temperature, moderate humidity, persistence of northerly trade winds, and rarely severe storms (Armstrong, 1973). There are two general seasons in Hawaii. Summer is between May and October when the sun is nearly overhead. The weather is warm and dry and the northeast trade winds are persistent. The winter season is between November and April. During this period the sun is in the south and the weather is cooler. Interruptions of the trade winds by other winds bring more frequent clouds and rain. In Hawaii, during most of the year, the trade winds are from the northeasterly direction and the windward side of Oahu is normal to this trade wind. Most of the time the northeast trade winds are strong near Nuuanu Pali and Kahuku.

Rainfall

The mean annual rainfall varies from 1,000 to 2,000 mm (40 to 80 in.) in the valleys and exceeds 6,000 mm (240 in.) at the summits of the Koolau Range in Windward Oahu. Rainfall distribution very often follows the contour of the elevation and the rainfall gradient exceeds 1,000 mm per km distance. In areas of low to moderate rainfall and in marginal agricultural areas, the median annual rainfall is often less than the mean annual rainfall. Hence, Halsted and Leopold (1948) recommended the median annual rainfall as a better index for agricultural uses. Kahuku and Kailua are in dry parts of Windward Oahu and receive only about 1,000 mm of median annual rainfall.

The median annual rainfall distribution for the island of Oahu is shown in Figure 3. The isohyets were based on the data from the year 1933 through 1957. The monthly rainfall distribution patterns of four rain gauge stations close to the soil sampling sites are presented in Figures 4 and 5.

Temperature

In Hawaii, variation in mean annual monthly temperature is usually less than 5 C. Mean annual temperature of Windward Oahu ranges from 23 to 25 C. The energy received from the sun as well as the temperature of surface waters of the ocean surrounding the Hawaiian islands are more or less constant throughout the year. The ocean temperature ranges from 22 C during the colder months to 27 C during the warmer months. Hence, the air that moves across the ocean near Hawaii is also mild resulting in more or less constant temperature, especially of the windward side of the islands (Blumestock and Price, 1967). The decrease in the mean monthly temperature is approximately 1 C for each 200 m in elevation.

Evapotranspiration

Evaporation of water vapor from soil and of free water from land surface and transpiration of plants constitute evapotranspiration. In Hawaii, annual variation in evapotranspiration is

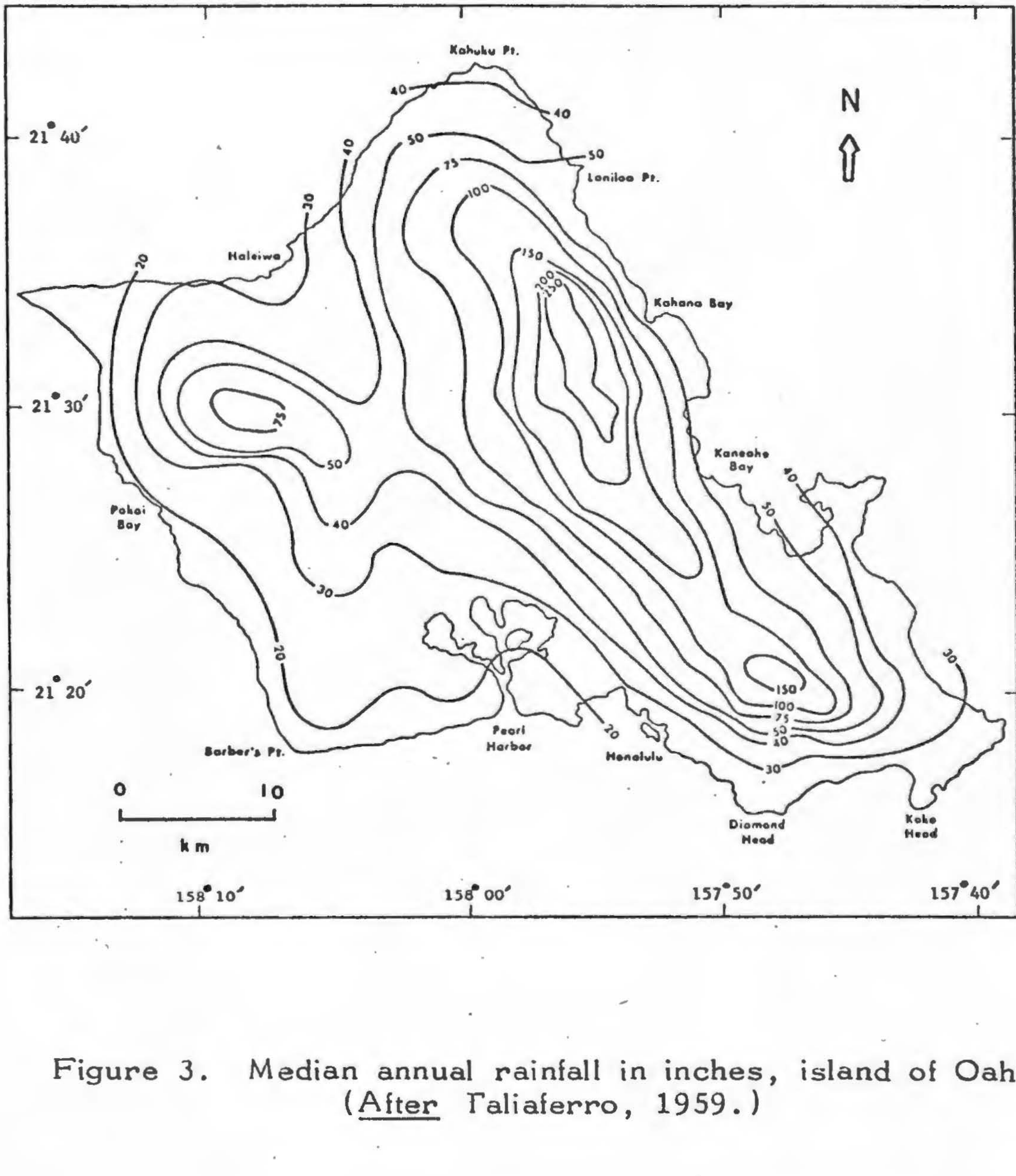


Figure 3. Median annual rainfall in inches, island of Oahu. (After Taliaferro, 1959.)

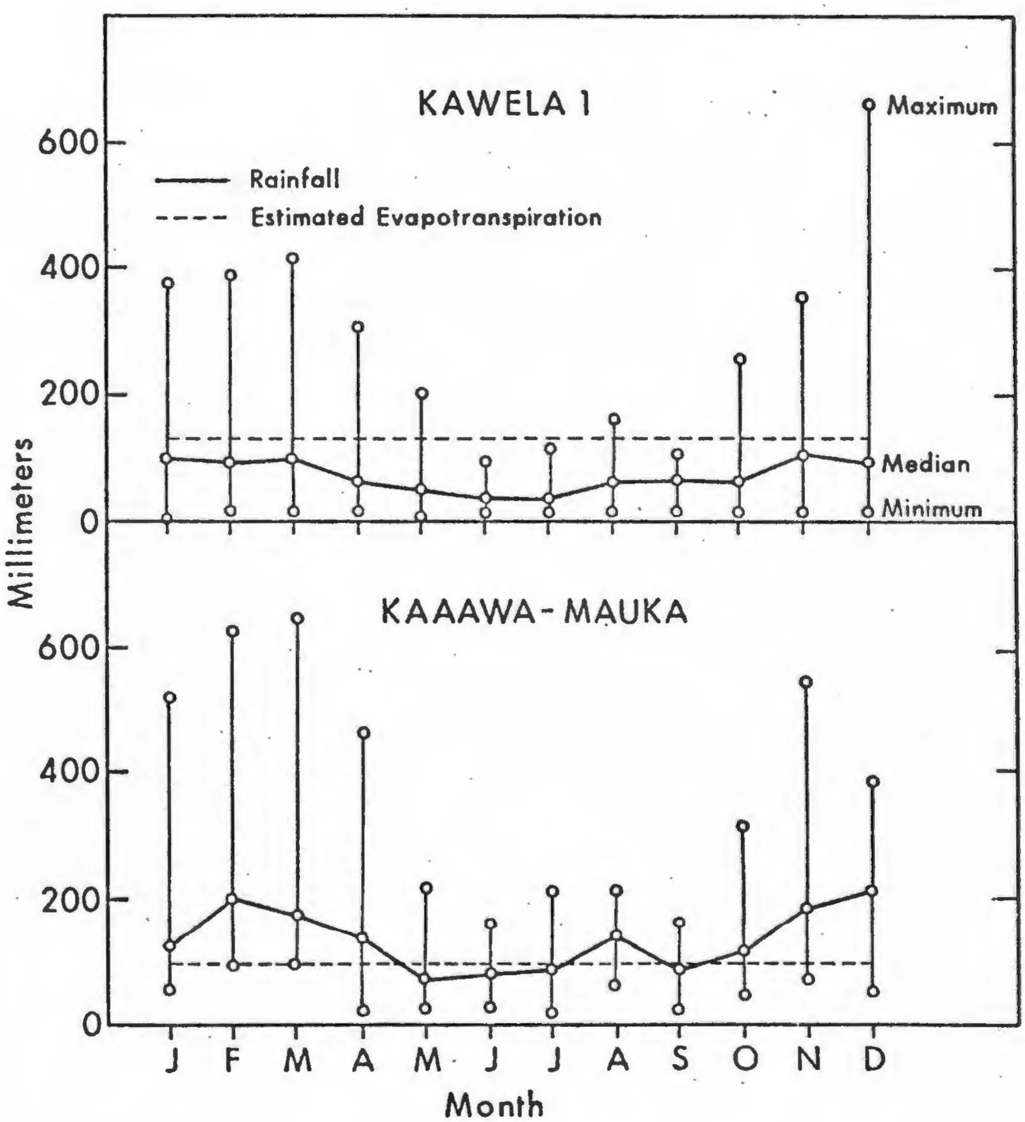


Figure 4. Monthly rainfall distribution and estimated potential evapotranspiration of climatologic stations Kawela 1 and Kaaawa Mauka.

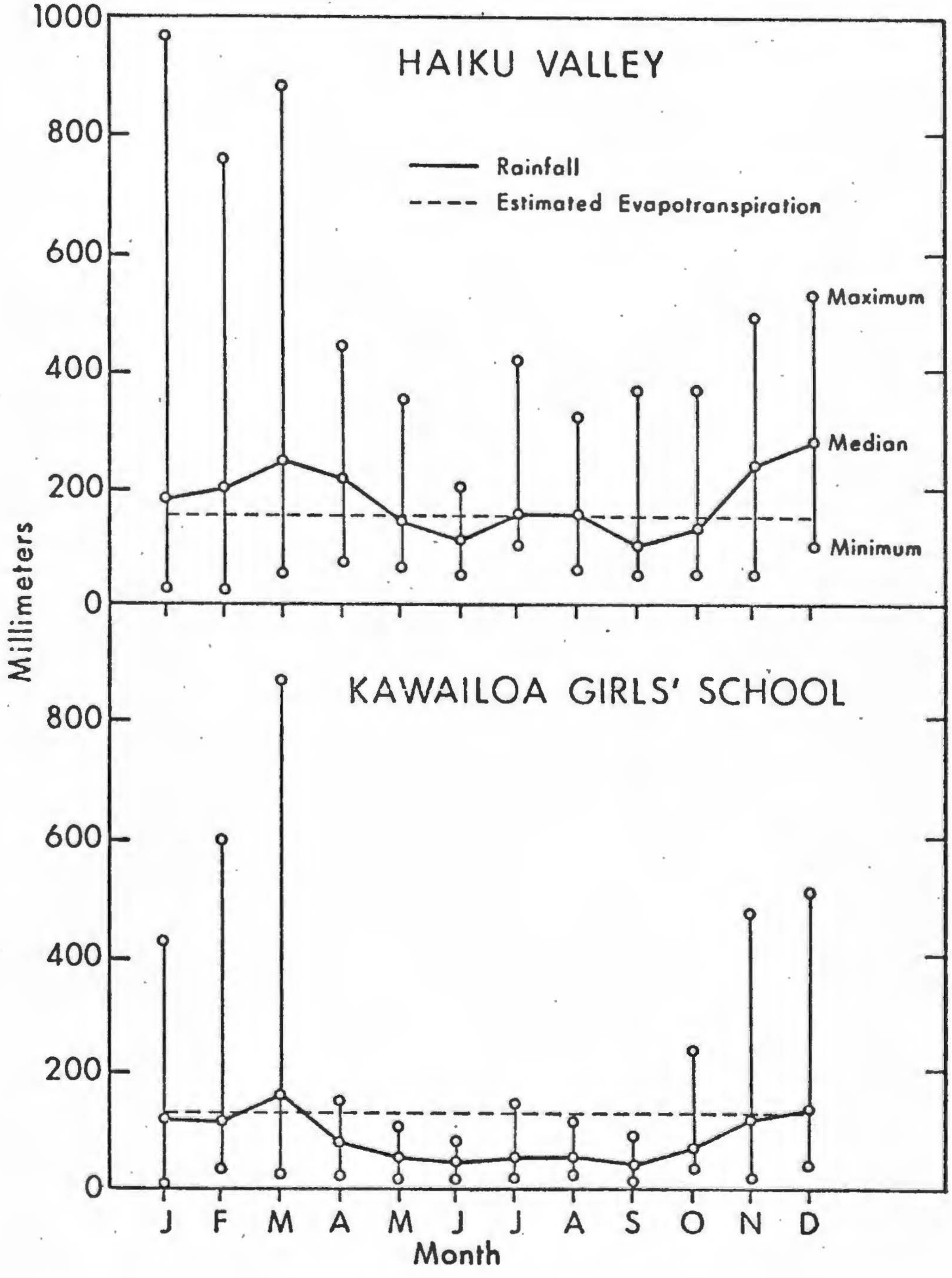


Figure 5. Monthly rainfall distribution and estimated potential evapotranspiration of climatologic stations Haiku Valley and Kawailoa Girls' School.

small due to small fluctuation in temperatures. Experience from sugar industries show that the evapotranspiration of irrigated sugar lands approximately equals pan evaporation (Takasaki and Valenciano, 1969). Frequent rains in Windward Oahu may suggest evapotranspiration values similar to those of potential evapotranspiration. Due to paucity of data for Windward Oahu, Takasaki and Valenciano (1969) developed a regression equation based on data from pan evaporation stations in Hawaii (Fig. 6). For areas with cumulative annual wind movements of less than 32,000 km, the following regression equation can be used to compute the median annual pan evapotranspiration.

$$\log_{10} E = 2.3435 - 0.001378\ R$$

Where E = Median annual pan evaporation in cm

R = Median annual rainfall in cm

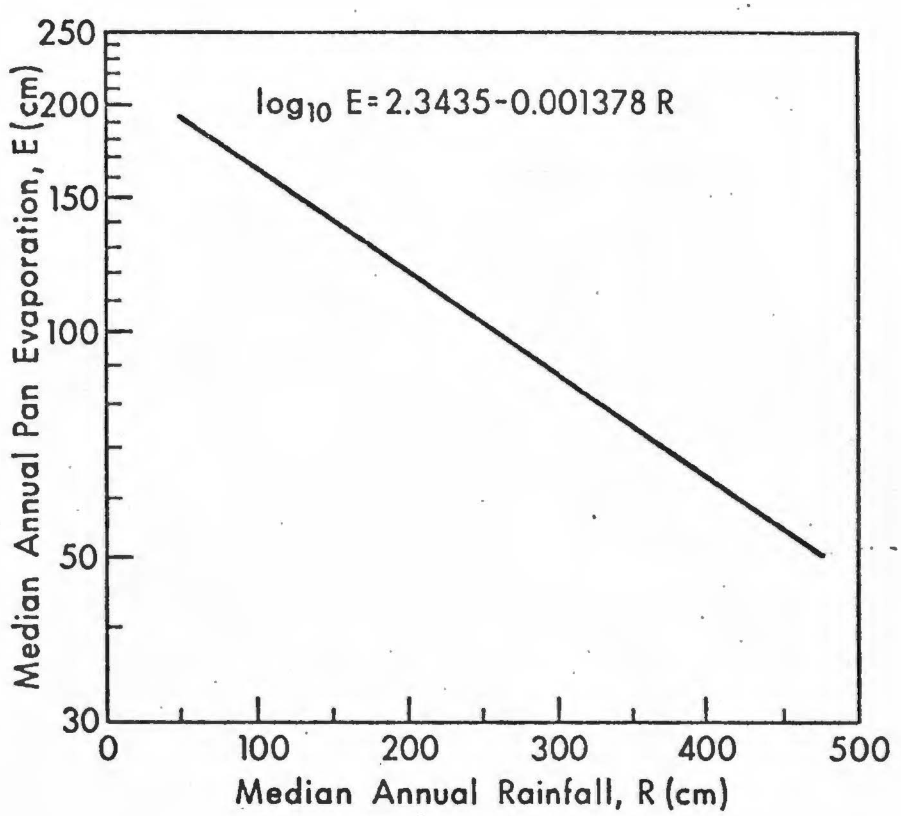


Figure 6. Relationship of median annual pan evaporation to median annual rainfall in the Hawaiian Islands. (After Takasaki and Valenciano, 1969.)

MATERIALS AND METHODS

Field Soil Sampling

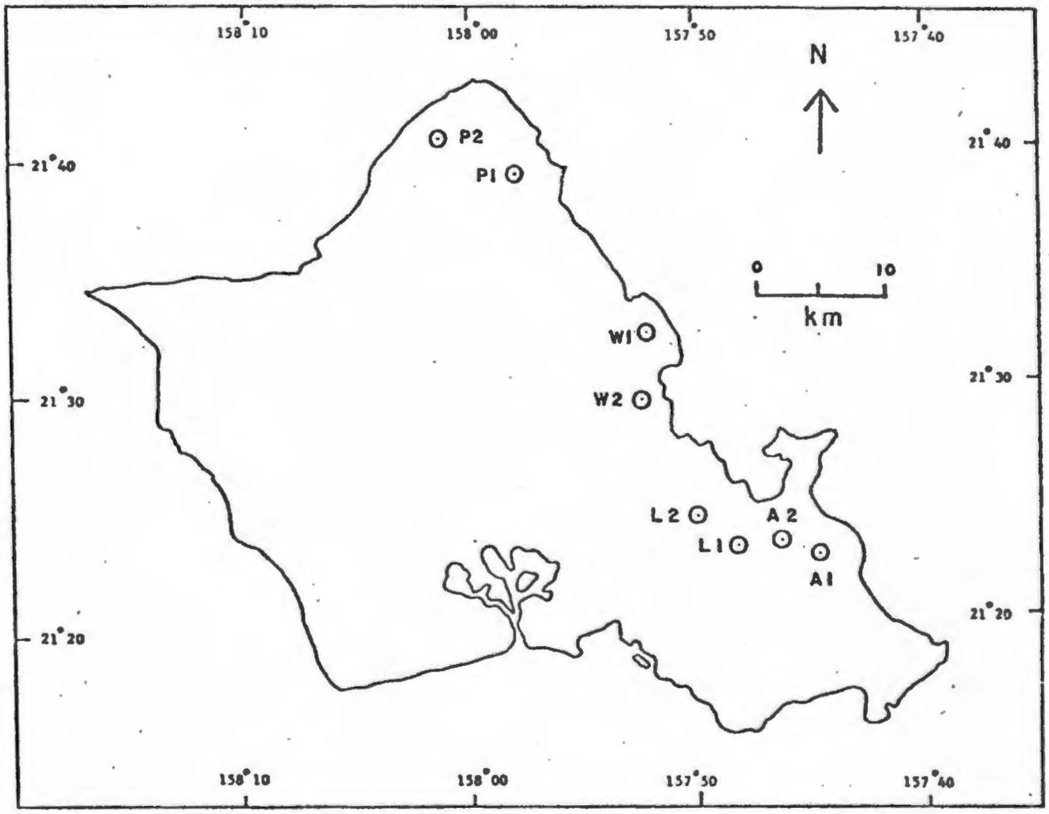
Two representative profiles of the Alaeloa, Lolekaa, Paumalu and Waikane soils were described and collected according to procedure prescribed in the Soil Survey Manual (Soil Survey Staff, 1951). The soil descriptions are presented in Appendix A. Bulk soil samples of each horizon were brought into the laboratory for analysis. Natural clods were preserved for the determination of bulk density and the preparation of thin sections. The locations of the sample sites are shown in Figure 7.

Laboratory Soil Preparation

A portion of the samples was processed to pass through a 2-mm sieve for analysis. Some of the moist field samples had to be air-dried and larger clods broken to pass through the sieve. Subsamples were further dried and ground to pass an 80-mesh (0.18 mm) sieve for the estimation of organic carbon and extractable iron. The processed soil samples were stored in double plastic bags.

Methods of Analysis

Methods of analysis were essentially those described in



A1--Alaeloa (Koolau Boys' Home)
A2--Alaeloa (Kapaa Quarry)
L1--Lolekaa (Kaneohe)
L2--Lolekaa (Haiku)
P1--Paumalu (Laie)
P2--Paumalu (Puu Kauweweole)
W1--Waikane (Kaaawa)
W2--Waikane (Waiahole)

Figure 7. Location of soil sampling sites in Windward Oahu.

Soil Survey Investigation Report No. 1 (Soil Survey Staff, 1972). The symbols in parentheses in the following sections correspond to the methods of analysis in the report.

Bulk Density

The bulk density measurements were made using the clod method (Blake, 1965).

Particle Size Distribution--Pipet method (3A1)

About 20 g of soil sample was treated with H_2O_2 to destroy the organic matter. No attempt was made to remove the electrolytes released. Ten ml of 5% sodium metaphosphate was added to disperse the soil particles and shaken for 16 hours. Particles greater than 50 μ were separated by using a 325 mesh (44 μ) sieve. Clay plus silt and clay were estimated by pipetting a 25 ml of the suspension at appropriate times.

Water Retention at 1/3- and 15-Bar Tensions

Gravimetric water contents retained at 1/3-bar and 15-bar tensions were determined using pressure plate apparatus (U. S. Salinity Laboratory Staff, 1954).

Soil pH (8C)

Soil pH's were determined in water and in 1N KCl using a ratio of 1:1.

Organic Carbon (6A1a)

Wet oxidation method of Walkley and Black was used to determine the organic carbon.

Cation Exchange Capacity--Ammonium Acetate (5A1b)

Cation exchange capacity was determined at pH 7 using 1N NH_4OAc. The excess NH_4OAc was removed with 95% methanol.

Exchangeable Bases and Base Saturation

Exchangeable Ca and Mg were determined in the NH_4OAc extract by using the Perkin-Elmer model 303 Atomic Absorption unit. Exchangeable Na and Mg were determined by means of a Beckman D.U. Flame Spectrophotometer.

Base saturation was calculated by dividing the exchangeable bases by the cation exchange capacity and expressed as percentage.

Extractable Acidity (6H1)

Extractable acidity was determined at pH 8.2 by back titrating the $BaCl_2$-triethanolamine buffer solution with 0.2 N HCl.

Cation Exchange Capacity--Sum of Cations (5A3a)

Cation exchange capacity was also computed by adding the sum of exchangeable Ca, Mg, Na, K, and the extractable acidity.

Extractable Aluminum (6G1d) and Aluminum Saturation

Aluminum was extracted with 1N KCl and determined volumetrically.

Aluminum saturation was calculated by dividing the exchangeable Al by the sum of exchangeable Ca, Mg, Na, K, and Al and expressed as percentage.

Extractable Iron (6C1)

Iron was reduced with $Na_2S_2O_4$ and determined by means of atomic absorption spectroscopy.

Phosphate Adsorption

Phosphate sorption isotherms were constructed by equilibrating three grams of soil for six days at 24 C in 30 ml of 0.01 M $CaCl_2$ containing varying amounts of $Ca(H_2PO_4)_2$ as outlined by Fox and Kamprath (1970).

Mineralogy

Mineralogy of the fine earth fraction was determined by means of Philips Norelco X-ray diffractometer. Copper $K\alpha$ radiation (50 KV and 25 mA) with a graphite monochrometer was used for the analysis of the clay, silt, and sand-size fractions obtained from the particle size determinations. Oriented clays of K-saturated specimen were scanned from 2° 2θ to 64° 2θ at room temperature and from 2° 2θ to 16° 2θ for 105 C, 300 C and 550 C heat treated specimens. Moist Mg-saturated clay pastes, mounted on glass slides, were scanned from 2° 2θ to 16° 2θ. Oriented silt specimen mounted on glass slides, and sand fraction, placed in aluminum sample holders, were scanned from 2° 2θ to 64° 2θ.

RESULTS AND DISCUSSION

Soil and Landscape Parameters

Soil Parameters

A study of the Soil Survey Laboratory Data and Descriptions for Some Soils of Hawaii (SCS et al., 1976) reveals the availability of data for 15 pedons of Ultisols representing 7 different soil series. Of these numbers, only one, the Lolekaa series, is collected from Windward Oahu. The remaining soils are collected from either Leeward Oahu, Maui, or Molokai.

The results of this investigation will contribute laboratory data of the more important or more common Ultisols of Windward Oahu and substantiate or modify the range in characteristics of the selected physical, chemical, and mineralogical properties of these soils and also of soils classified in the same category.

Soil parameters relevant to agricultural uses are many and of varying importance. For agricultural uses, properties such as depth of soil, depth of water table, stoniness, structure, hardpan, gleying, cat-clays, particle size distribution, mineralogy, organic matter, salinity and alkalinity, acidity, and base saturation are important. Along with many of the above-mentioned properties shrink-swell potential, compressibility, shear strength and bearing capacity need to be considered for nonagricultural uses. Some of the present and potential uses of Ultisols of Windward

Oahu are for truck crops, fruit crops, pasture, forestry, dwellings, roads and road banks, sewer and water disposal.

Physical, chemical, and mineralogical properties relevant to soil classification and for selected agricultural and nonagricultural uses are discussed in the following sections. The morphological properties are described in Appendix A.

Physical Properties

Bulk Density. The bulk density values are given in Table 2. The values determined by the clod methods are in general slightly higher than the other methods according to Blake (1965), Goddard et al. (1971), and Harlan and Franzmeier (1974).

Among the soils, the Alaeloa soils at site A2 (Kapaa Quarry) had the highest bulk density values, ranging from 1.28 to 1.48 g/cm^3. These high values are due to the appreciable amounts of quartz in the silt and sand-size fractions. In many cases, when the bulk density exceeds 1.5 or 1.6 g/cm^3, root penetration becomes a problem (Russell, 1973). On the other hand, the bulk density values of the Waikane soils and the Lolekaa soil at site L1 (Kaneohe) were about 1.03 g/cm^3. The soils had small to moderate amounts of X-ray amorphous materials. The lack of peaks that are attributed to crystalline minerals was used to estimate the presence of X-ray amorphous materials.

Table 3. Physical Properties of Eight Soils of Windward Oahu

Depth	Horizon	Particle Size			Textural Class	Bulk Density	Water Retention		
		Sand	Silt	Clay			1/3-atm	15-atm	1/3-atm - 15-atm
cm		----------% wt----------				g/cc	-------------- % wt --------------		
				Alaeloa - Site A1 (Koolau Boys' Home)					
0- 18	A1	24.1	36.6	39.3	Clay loam	1.12	26.6	19.4	7.2
18- 30	B21	6.3	22.2	71.5	Clay	1.07	33.5	28.0	5.5
30- 52	B22t	4.0	18.2	77.8	Clay	0.94	38.8	31.1	7.7
52- 85	B23t	5.1	19.9	75.0	Clay	1.13	39.0	33.5	5.5
85-115	B24t	5.9	25.4	68.7	Clay	1.13	39.7	35.3	4.4
115-135	B25t	7.2	26.8	66.0	Clay	1.15	43.0	34.7	8.3
135-150	B26t	9.6	32.5	57.9	Clay	1.19	43.7	35.6	8.1
150-170	B27	8.6	36.4	55.0	Clay	1.12	42.9	34.5	8.4
				Alaeloa - Site A2 (Kapaa Quarry)					
0- 14	A11	33.4	32.2	34.4	Clay loam	1.42	24.0	14.7	9.3
14- 24	A12	27.3	33.6	39.1	Clay loam	1.40	27.5	19.4	8.1
24- 40	B21t	10.2	22.5	67.3	Clay	1.28	37.5	29.6	7.9
40- 75	B22t	7.7	25.2	67.1	Clay	1.35	37.8	31.3	6.5
75-103	B23t	10.7	16.7	72.6	Clay	1.36	36.7	28.7	8.0
103-135	B24t	13.2	28.8	58.0	Clay	1.40	36.2	27.8	8.4
				Lolekaa - Site L1 (Kaneohe)					
0- 16	Ap1	3.7	28.1	68.2	Clay	0.96	40.4	33.7	6.7
16- 36	B21	5.3	31.8	62.9	Clay	1.13	42.9	34.8	8.1
36- 63	B22t	7.7	32.8	59.5	Clay	1.06	48.1	40.9	7.2
63- 99	B23t	10.9	32.6	56.5	Clay	1.02	52.7	42.8	9.9
99-130	B24t	12.7	33.5	53.8	Clay	0.99	47.1	42.5	4.6
130-160	B25t	21.8	30.5	47.7	Clay	1.04	46.8	39.3	7.5
160-190	B26t	25.6	31.8	42.6	Clay	1.02	48.5	39.0	9.5
				Lolekaa - Site L2 (Haiku)					
0- 4	A11	22.0	36.1	41.9	Clay	1.25	32.3	24.3	8.0
4- 23	A12	16.8	34.1	49.1	Clay	0.54	58.7	49.8	8.9
23- 62	B21	10.0	26.6	63.4	Clay	0.75	61.0	55.9	5.1
62- 94	B22	14.8	30.0	55.2	Clay	0.87	61.2	51.0	10.2
94-125	B23	8.4	30.7	60.9	Clay	0.88	61.4	52.2	9.2
125-160	B24	20.6	44.1	35.3	Clay loam	0.90	48.0	37.7	10.3
160-190	B25	18.5	51.5	30.0	Silty clay loam	0.88	49.7	38.7	11.0
				Paumalu - Site P1 (Laie)					
0- 24	A1	2.8	32.4	64.8	Clay	1.29	37.5	30.3	7.2
24- 52	B21t	0.8	10.9	88.3	Clay	1.19	53.0	42.5	10.5
52- 78	B22t	1.6	16.5	81.9	Clay	1.14	51.1	42.5	8.6
78-117	B23t	5.7	25.8	68.5	Clay	1.27	45.6	38.3	7.3
117-155	B24t	7.8	24.1	68.1	Clay	1.25	46.2	39.0	7.2
155-190	B25t	11.7	28.5	59.8	Clay	1.32	45.7	37.2	8.5
				Paumalu - Site P2 (Puu Kauweweole)					
0- 18	A11	6.1	42.9	51.0	Clay	1.30	34.2	26.1	8.1
18- 41	A12	8.5	40.5	51.0	Clay	1.24	31.7	27.1	4.6
41- 72	B21t	6.7	24.2	69.1	Clay	1.08	45.9	40.8	5.1
72-100	B22t	11.3	26.4	62.3	Clay	1.10	45.6	37.5	8.1
100-120	B23t	14.8	28.8	56.4	Clay	1.19	45.2	37.6	7.6
120-140	B24t	15.7	28.6	55.7	Clay	1.17	44.7	38.1	6.6
				Waikane - Site W1 (Kaaawa)					
0- 15	Ap1	2.0	32.3	65.7	Clay	1.04	40.8	32.5	8.3
15- 35	B21	4.4	28.1	67.5	Clay	0.92	49.2	41.8	7.4
35- 60	B22t	5.2	28.9	65.9	Clay	1.03	49.0	43.7	5.3
60- 85	B23t	6.0	30.9	63.1	Clay	1.02	50.9	42.8	8.1
85-115	B24t	9.7	30.6	59.7	Clay	1.09	51.2	43.3	7.9
115-140	B25t	12.2	35.6	52.2	Clay	1.10	48.1	41.5	6.6
140-160	B26	10.4	32.0	57.6	Clay	1.09	50.3	41.5	8.8
160-190	B27	9.6	35.5	54.9	Clay	1.00	52.8	43.5	9.3
				Waikane - Site W2 (Waiahole)					
0- 16	Ap1	9.0	43.2	47.8	Silty clay	1.08	32.0	26.7	5.3
16- 28	B21	8.4	39.4	52.2	Clay	1.17	34.7	28.5	6.2
28- 46	B22t	4.1	30.0	65.9	Clay	1.07	44.8	39.5	5.3
46- 76	B23t	5.5	36.3	58.2	Clay	1.04	49.4	43.5	5.9
76- 99	B24t	10.9	35.4	53.7	Clay	0.95	49.2	38.7	10.5
99-142	B25t	14.4	35.9	49.7	Clay	1.04	51.6	40.2	11.4
142-168	C1	16.5	40.4	43.1	Clay	0.93	58.7	47.2	11.5

The Lolekaa soils at site L2 (Haiku) had bulk density values ranging from 0.54 to 0.88 g/cm^3 except at the surface. The top four cm of soil had a bulk density of 1.25 g/cm^3 and may be due to aggregation or dehydration. Bulk density values of 0.85 g/cm^3 or less indicate the presence of significant amounts of volcanic ash and/or pumice in mineral soils (Soil Survey Staff, 1973). This sampling site is close to the post-erosional volcanic vent of Haiku and the mineralogical study of this soil reveals the presence of appreciable amounts of X-ray amorphous materials and of small amounts of goethite, kaolin, and 2:1 interstratified minerals. Soils with low bulk density values are usually associated with high total porosity.

Because the bulk density values range from 0.54 to 1.42 g/cm^3 in the soils studied, they must be taken into account when analytical results expressed on weight basis and are compared with each other.

Soil Texture. Soil texture refers to the relative proportion of sand, silt, and clay-size particles of the fine earth fraction (2 mm or less). Many of the physical and chemical reactions take place at the surface of the particles and hence texture is important. Textural classes are related to plasticity, permeability, ease of tillage, water storage characteristics, and shrink-swell potential. Soil texture influences pedological, physical, chemical, and biological properties of soil and does not change. In Soil Taxonomy (Soil Survey Staff, 1973), texture is considered at the soil family level. In the soils of the tropics, especially soils derived from basaltic parent material, the sand, silt, and clay contents may not have precise meaning because of aggregation. Soils dominated by kaolinite or certain oxides or hydroxides of iron and aluminum form aggregates and behave like medium textured soils.

Particle size distribution of the fine earth fraction and textural classes are presented in Table 2. Clay-size fractions dominate these soils followed by silt and sand-size fractions. Most of the soils are clayey in texture except the surface horizon of Alaeloa soils and Waikane soil at site W2 (Waiahole) and the lower horizons (B24 and B25) of the Lolekaa soil at site L2 (Haiku). The surface horizons of the Alaeloa soils have appreciable amounts of hydrothermally produced quartz in the sand and silt-size fractions.

The clay contents range from 30 to 88% while the silts range from 10 to 51% and the sands from 1 to 33%. The pattern of particle size distribution reveals the absence of lithological discontinuity. In most of the soils, the silt and sand-size fractions are aggregates of weathered minerals. The clay contents increase in the subsoil and then decrease, except in the Lolekaa soil at site L1 (Kaneohe) and in the Waikane soil at site W1 (Kaaawa). The particle size or textural class data, therefore, reflects the stability of aggregates when the soils of the study site are analyzed according to the method of Kilmer and Alexander (1949).

<u>Soil Structure</u>. The combination or arrangement of primary particles lead to various structures in soil. For optimum growth of plants, the soil should provide nutrients, water, and oxygen. The availability of these components are influenced by soil structure and texture. Often, structure overrides the influence of texture on the air-water relationships and nutrient availability. In well-structured soils, texture may not be a good indicator of soil water characteristics.

Soil structure is influenced by mineralogy of the fine earth fractions, organic matter, texture, and the nature of exchangeable cations. Oxides and hydroxides of iron and aluminum, when present in sufficient amounts, are known to bind the smaller particles into larger aggregates as a continuous matrix. Gel-like amorphous coatings of hydrous alumino-silicates on soil particles help bind the soil particles according to Jones and Uehara (1974). Mutual flocculation between positively and negatively charged surfaces in highly weathered soils can also lead to well-aggregated structure (El-Swaify and Emerson, 1975).

Water movement and retention are greatly influenced by soil structure. In well-aggregated soils of the Molokai Series (Typic Torrox) and the Wahiawa Series (Tropeptic Eutrustox), rapid release of water at low tension and the high water contents at high tensions are related to inter-aggregate and intra-aggregate pores (Sharma, 1966). The presence of these voids in Oxisols and Ultisols of Hawaii having kaolin and oxide mineralogy are illustrated by means of scanning electron micrographs (Tsuji et al., 1975). Macropores aid in free drainage after heavy rains and intra-aggregate voids help in water storage and in making water available to plants over an extended period of time. A high steady state infiltration rate of 2.9 cm/hour was reported for Waikane soil by Dangler et al. (1975).

The surface horizons of Alaeloa, Lolekaa, Paumalu, and Waikane soils usually have strong, fine and very fine subangular blocky structure (Appendix A). Most of the subsurface horizons of the Alaeloa soil at site A2 (Kapaa Quarry) and the Waikane soil of site W1 (Kaaawa) have moderate, medium subangular blocky structure. The subsurface horizons of the other soils have moderate, fine and very fine subangular blocky or sometimes moderate fine granular structure. Hence, these soils have many favorable physical properties associated with the subangular blocky or granular structure.

Water Retention. The gravimetric water retention data at 1/3-bar and 15-bar tensions are presented in Table 2. The 15-bar water retention varied from 14 to 51%. The Alaeloa soils had low water retention due to the large amounts of quartz in the coarse fractions. These soils also have high bulk density values. The Lolekaa soils had the highest water retention among the four soil series studied. These soils have appreciable amounts of amorphous materials and low bulk density values. Amorphous materials are reported to have high 15-bar water retention due to large surface area (Buol et al., 1973; Warkentin and Maeda, 1974). The Waikane soils also have small to moderate amounts of amorphous materials and have high 15-bar water retention.

The difference between 15-bar and 1/3-bar water contents is considered as available water. The amount of soil moisture retained in a form readily available to plants is controlled by various soil properties, such as texture, organic matter, coarse fragments, bulk density, and structure. Total moisture holding capacity usually increases with decreasing particle size, and available water holding capacity increases with increasing silt size. Available water content varies from 4 to 12%. Due to variations in bulk density values from 0.54 to 1.42, volumetric water content is expected to vary.

Chemical Properties

Soil pH. The Ultisols are highly leached soils resulting in low base saturation and strong acidic reaction. Availability of plant nutrients, lime requirement, and crop productivity in general are greatly influenced by the nature and extent of soil acidity. Low soil pH also corrodes metal and deteriorates concrete emplacements.

The pH values in water and 1N KCl are presented in Table 3. The delta pH values (pH in KCl minus pH in water) are negative and indicate that the net surface charge is negative (Mekaru and Uehara, 1972). The pH values of the Ultisols range from 4.5 to 5.4. The pH values generally decrease with depth except in the Lolekaa soils at site L2 (Haiku) and in the Waikane soils at site W2 (Waiahole).

The pH values of the Alaeloa soil at site A1 (Koolau Boys' Home) range from 4.7 to 6.5. This soil also has high percentage of base saturation ranging from 45 to 71 among different horizons. According to Soil Taxonomy (Soil Survey Staff, 1973), this particular soil does not qualify for an Ultisol because of the high base saturation.

Organic Carbon. The organic carbon contents are shown in Table 3. Organic matter values can be obtained by multiplying organic C by a factor of 1.724. All of the soils in this study have more than 0.9% organic C in the upper 15 cm of the argillic horizon and contain more than 12 kg of organic C in an area of a square meter to a depth of one meter. Thus, these soils qualify as Humults.

Organic C contents and exchangeable bases usually decrease with depth. Organic matter is a source of N, P, S, and other plant nutrients. Organic matter also serves as a binding agent

Table 3. Chemical Properties of Eight Soils of Windward Oahu

Depth	Horizon	Organic Carbon	pH KCl	pH H_2O	pH ΔpH	Exchangeable Ca	Exchangeable Mg	Exchangeable Na	Exchangeable K	Extract. Acidity	Sum of Cations	Base Sat.	Exch. Al	Al Sat.	CEC (NH_4OAc) Soil	CEC (NH_4OAc) Clay	Cat. Ret. Clay	Extract. Iron
cm		%				---------------meq/100 g---------------						%	muq/100 g	%	------ meq/100 g-------			%
						Alaeloa - Site A1 (Koolau Boys' Home)												
0- 18	A1	3.37	5.49	6.52	-1.03	2.33	8.73	0.20	0.79	4.87	16.92	71	0.00	0	14.97	38.09	30.6	3.87
18- 30	B21	1.19	4.17	5.07	-0.90	2.10	8.73	0.20	0.79	8.33	20.15	58	0.10	0	17.51	24.48	17.6	6.42
30- 52	B22t	1.08	3.96	4.76	-0.80	1.71	7.60	0.40	0.72	11.01	21.44	47	2.55	19	19.18	24.65	16.1	5.31
52- 85	B23t	0.76	3.94	4.84	-0.90	0.89	8.29	0.32	0.08	11.71	21.29	44	4.97	34	22.87	30.49	19.4	7.29
85-115	B24t	0.46	3.94	4.66	-0.72	0.33	9.03	0.82	0.06	11.27	21.51	47	4.23	29	23.37	31.16	21.0	6.63
115-135	B25t	0.38	3.87	4.60	-0.73	0.17	9.42	0.52	0.06	10.85	21.02	48	4.12	28	24.52	37.15	21.7	6.15
135-150	B26t	0.33	3.80	4.73	-0.93	0.07	9.42	0.75	0.04	9.98	20.26	50	4.80	31	23.11	39.91	26.0	5.93
150-170	B27	0.24	3.81	4.71	-0.90	0.02	9.50	0.66	0.09	10.98	21.25	48	4.61	30	22.78	41.41	27.0	5.95
						Alaeloa - Site A2 (Kapaa Quarry)												
0- 14	A11	1.50	4.81	5.45	-0.64	2.20	2.18	0.33	0.47	8.66	13.84	37	0.00	0	9.00	26.16	16.0	4.91
14- 24	A12	1.70	4.35	5.26	-0.91	1.27	1.22	0.26	0.31	10.47	13.53	22	0.93	23	8.88	22.71	10.2	6.06
24- 40	B21t	1.83	4.43	5.30	-0.87	1.88	2.62	0.36	0.33	12.86	18.05	28	1.43	21	12.97	19.27	9.8	9.20
40- 75	B22t	1.02	4.10	4.96	-0.86	1.16	2.11	0.37	0.18	13.18	17.00	22	3.14	45	14.12	21.04	10.3	10.67
75-103	B23t	0.70	4.02	4.87	-0.85	0.89	1.26	0.31	0.07	12.59	15.12	16	4.92	66	12.75	17.56	10.3	10.47
103-135	B24t	0.54	4.01	4.90	-0.89	0.69	0.98	0.32	0.07	12.21	14.27	14	4.78	69	12.64	21.79	11.8	9.47
						Lolekaa - Site L1 (Kaneohe)												
0- 16	Ap1	4.50	4.01	4.90	-0.89	2.53	2.68	0.40	0.42	19.53	25.56	23	3.99	39	25.53	37.43	14.7	7.93
16- 36	B21	1.08	3.97	5.25	-1.28	2.59	2.86	0.97	0.19	16.21	22.82	28	6.58	49	32.76	52.08	20.9	6.34
36- 63	B22t	0.58	3.90	5.27	-1.37	1.89	2.16	1.10	0.09	19.37	24.61	21	9.11	63	30.00	50.42	24.1	5.90
63- 99	B23t	0.54	3.79	4.86	-1.07	1.27	1.28	0.87	0.21	18.97	22.60	16	10.38	74	30.53	54.03	24.7	6.99
99-130	B24t	0.68	3.79	4.98	-1.19	0.91	0.87	0.79	0.33	17.20	20.10	14	9.40	76	28.41	52.80	22.8	9.46
130-160	B25t	0.57	3.82	4.91	-1.09	0.75	0.74	0.62	0.33	18.71	21.15	11	9.00	78	28.90	60.58	23.9	11.55
160-190	B26t	0.53	3.76	4.84	-1.08	0.62	0.56	0.63	0.32	19.67	21.80	9	9.26	81	22.66	53.19	26.7	9.87
						Lolekaa - Site L2 (Haiku)												
0- 4	A11	4.84	4.21	4.79	-0.58	0.38	1.52	0.31	0.15	16.78	19.14	12	1.63	40	30.32	72.36	9.5	9.58
4- 23	A12	6.43	4.07	4.82	-0.75	0.25	0.85	0.38	0.12	19.45	21.05	7	3.70	69	35.96	73.23	10.8	9.11
23- 62	B21	1.74	4.19	5.50	-1.31	0.01	0.34	0.34	0.04	17.49	18.22	4	3.38	82	27.57	43.48	6.4	12.73
62- 94	B22	1.20	4.05	5.34	-1.29	0.05	0.37	0.43	0.06	18.73	19.64	4	5.41	85	27.98	50.68	11.4	11.31
94-125	B23	0.89	4.10	5.43	-1.33	0.07	0.31	0.28	0.05	17.24	17.95	3	4.70	86	18.33	30.09	8.8	11.43
125-160	B24	0.31	3.97	5.52	-1.55	0.04	0.41	0.35	0.04	18.58	19.42	4	9.10	91	19.92	56.43	28.1	11.48
160-190	B25	0.39	3.92	5.30	-1.38	0.01	0.35	0.42	0.05	19.54	20.37	3	7.98	90	20.47	68.23	29.0	11.32
						Paumalu - Site P1 (Laie)												
0- 24	A1	4.01	4.08	4.66	-0.58	2.94	6.35	0.37	0.49	11.78	21.93	46	0.94	8	28.03	43.25	7.5	8.60
24- 52	B21t	1.83	3.84	4.70	-0.86	1.79	5.74	0.39	0.17	16.85	24.94	32	6.35	43	32.08	36.33	16.3	8.14
52- 78	B22t	1.03	3.80	4.70	-0.90	1.11	3.68	0.34	0.08	16.94	22.15	23	8.61	62	30.61	37.37	16.8	8.07
78-117	B23t	0.37	3.73	4.68	-0.95	0.50	2.59	0.47	0.05	16.60	20.21	17	9.40	72	35.07	51.19	18.9	8.49
117-155	B24t	0.14	3.63	4.52	-0.89	0.29	2.03	0.47	0.07	19.38	22.24	12	10.54	78	21.68	31.83	19.6	8.48
155-190	B25t	0.22	3.68	4.62	-0.94	0.21	1.83	0.47	0.07	19.83	22.41	11	12.07	82	23.26	38.89	24.5	8.04
						Paumalu - Site P2 (Puu Kauweweole)												
0- 18	A11	3.82	4.58	5.03	-0.45	2.49	2.78	0.47	0.76	10.95	17.45	37	0.13	1	21.25	41.66	13.0	10.81
18- 41	A12	2.80	4.60	5.01	-0.41	2.69	1.98	0.52	0.48	10.66	16.33	34	0.13	2	22.13	43.39	11.3	10.63
41- 72	B21t	1.44	4.38	4.79	-0.41	2.74	2.78	0.55	0.29	11.32	17.68	35	0.57	8	21.34	30.88	10.0	11.40
72-100	B22t	0.57	3.89	4.69	-0.80	0.99	1.45	0.44	0.17	11.33	14.38	21	2.90	48	17.08	27.41	9.5	10.92
100-120	B23t	0.36	3.79	4.38	-0.59	0.62	1.09	0.44	0.22	11.64	14.01	16	4.19	63	14.70	26.06	11.6	11.18
120-140	B24t	0.39	3.79	4.66	-0.87	0.53	1.01	0.44	0.22	13.40	15.60	14	3.97	64	14.77	26.51	11.0	11.85
						Waikane - Site W1 (Kaaawa)												
0- 15	Ap1	4.30	4.02	4.92	-0.90	1.87	2.05	0.43	0.39	16.66	21.40	22	2.71	36	21.24	32.3	11.3	6.19
15- 35	B21	1.36	3.91	5.04	-1.13	0.81	1.16	0.68	0.17	19.94	22.76	12	7.59	72	21.19	31.4	15.4	6.64
35- 60	B22t	1.75	3.88	5.06	-1.18	0.73	1.12	0.69	0.05	18.84	21.43	12	7.74	74	20.55	31.1	15.6	8.17
60- 85	B23t	1.15	3.87	5.02	-1.15	0.52	1.01	0.61	0.07	18.13	20.34	10	9.20	80	22.36	35.4	18.4	7.95
85-115	B24t	0.78	3.84	4.99	-1.15	0.31	0.85	0.53	0.13	18.42	20.24	8	9.80	84	20.38	34.0	20.4	7.75
115-140	B25t	0.57	3.81	4.97	-1.16	0.36	0.86	0.50	0.16	17.24	19.12	9	10.30	84	20.67	39.5	23.3	8.32
140-160	B26	0.55	3.77	4.90	-1.13	0.27	0.54	0.50	0.24	14.99	16.54	9	9.63	86	20.41	35.4	19.4	7.65
160-190	B27	0.62	3.81	4.97	-1.16	0.24	0.61	0.44	0.14	15.40	16.83	8	10.76	88	16.98	30.9	22.2	7.34
						Waikanu - Site W2 (Waiahole)												
0- 16	Ap1	3.50	4.34	4.94	-0.60	2.79	1.35	0.39	0.12	14.57	19.22	24	0.85	15	19.69	41.19	11.5	12.30
16- 28	B21	3.43	4.25	4.96	-0.71	2.45	0.52	0.22	0.35	16.09	19.63	18	1.30	26	19.09	36.57	9.2	12.77
28- 46	B22t	2.00	4.05	4.84	-0.79	1.69	0.42	0.28	0.46	15.70	18.55	15	3.09	52	19.86	30.13	9.0	11.77
46- 76	B23t	1.36	3.94	4.88	-0.94	1.70	0.67	0.41	0.47	16.98	20.33	16	5.60	63	22.83	39.22	15.2	10.16
76- 99	B24t	0.88	3.94	4.96	-1.02	1.18	0.59	0.35	0.40	15.75	18.27	13	6.02	70	21.98	40.93	15.9	10.04
99-142	B25t	0.66	3.89	5.01	-1.12	0.67	0.30	0.25	0.40	16.49	18.11	8	6.67	80	17.68	35.57	16.6	9.77
142-168	C1	0.81	3.85	5.00	-1.15	0.68	0.48	0.30	0.51	18.28	20.25	9	7.56	79	21.62	50.16	22.1	9.57

for soil particles. Increasing amounts of organic matter decrease the exchangeable Al content at a given soil pH (Thomas, 1975). Organic matter plays an important role in supplying plant nutrients and maintaining favorable physical properties, especially in Ultisols.

Among the soils, the Alaeloa soils have the lowest organic matter content. These soils occur in a low rainfall area when compared with areas of other soils. In addition, large amounts of quartz in the silt and sand-size fractions have a dilution effect on the organic matter percentage.

The role of organic matter in reducing Al toxicity is discussed in the section dealing with Al.

<u>Cation Exchange Capacity</u>. The magnitude of cation exchange capacity (CEC) indicates the capacity of the soil to retain cations, the degree of weathering, and the general chemical activity. The nature and amount of clay minerals and the amount of organic matter determine the extent of CEC. Acid mineral soils with high CEC will usually have large amounts of exchangeable Al.

The CEC values determined by the sum of cation range from 13 to 25 meq/100 g soil (Table 3) and indicate a moderate clay activity. Many of the soils have appreciable amounts of amorphous materials, mica, or 2:1 intergrades (Table 5) which contribute to high CEC values. Gamble and Daniels (1974) have attributed a high CEC value to the presence of 2:1 to 2:2 intergrade minerals.

Among the soils, the Alaeloa soil at site A2 (Kapaa Quarry) has the lowest CEC values ranging from 13 to 18 meq/100 g soil. The clay fraction of this soil is dominantly kaolinitic. The sand fraction is dominantly quartz of hydrothermal origin and possesses low exchange capacity. The soils of Alaeloa (site A1), Lolekaa (site L1), Paumalu (site P1), and Waikane (site W1) occur in a comparatively low rainfall area and have slightly higher CEC than the other soils.

In general, CEC by the sum of cations determined at pH 8.2 is generally higher than CEC determined at pH 7 because of pH dependent charges. CEC values of Windward Oahu soils, however, are similar or lower at pH 8.2 than at pH 7 (Table 3). These results are due to the low value of extractable acidity determined with $BaCl_2$ - TEA in these highly aggregated soils. A period of 30 minutes may not have been sufficient to equilibrate these soils. Peech et al. (1962) reported an increase in the extractable acidity from 9 to 54% by equilibrating for one day instead of 30 minutes. They, therefore, recommended an equilibration time of one day and modified the procedure.

Base Saturation. Ultisols by definition have less than 35% base saturation by the sum of cations at a depth of 1.25 m below the upper boundary of the argillic horizon or 1.8 m below the surface of the soil, whichever is deeper (Soil Survey Staff, 1973). The Alaeloa soil at site A1 (Koolau Boys' Home) has an argillic horizon and a base saturation greater than 48% at a depth of 150 to 170 cm (Table 3) and thus is classified as an Alfisol.

Base saturation of the different horizons of the Ultisols ranges from 4 to 46% and generally decreases with depth in each of the pedons. The higher base saturation in the surface horizons of these soils may be due to biocycling by plants which brings bases from lower depths (Buol et al., 1973; Soil Survey Staff, 1973). For crop production, surface soil layers should be preserved. Exposing the subsoils with low base saturation may decrease the base supplying power.

Exchangeable Cations. The distribution of exchangeable Ca, Mg, Na, K and Al of different soils are illustrated in Figures 8 through 11. The sum of exchangeable Ca, Mg, Na, K, and Al may be considered the effective CEC (ECEC) (unpublished report, Uehara, 1975) although the sum of exchangeable Al, Ca, and Mg is suggested as effective CEC (ECEC) by Coleman et al. (1964). In each of the four soil series, site 1's (Alaeloa at site A1, Lolekaa at site L1, Paumalu at site P1, and Waikane at site W1) have higher ECEC than site 2's. Site 1's are located nearer to the sea. Furthermore, they are in areas of comparatively lower rainfall than

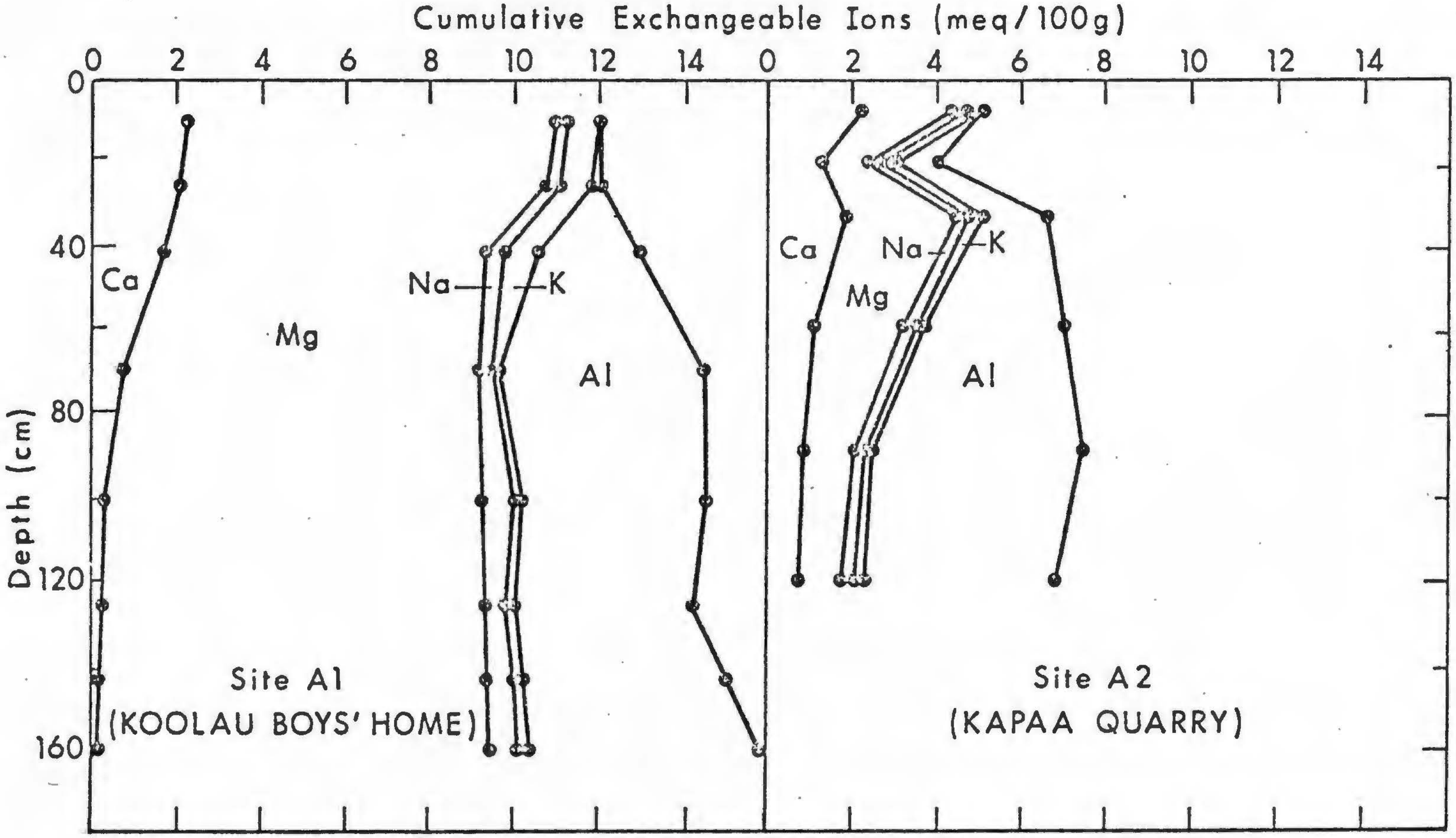


Figure 8. Cumulative distribution of exchangeable cations in the Alaeloa soils.

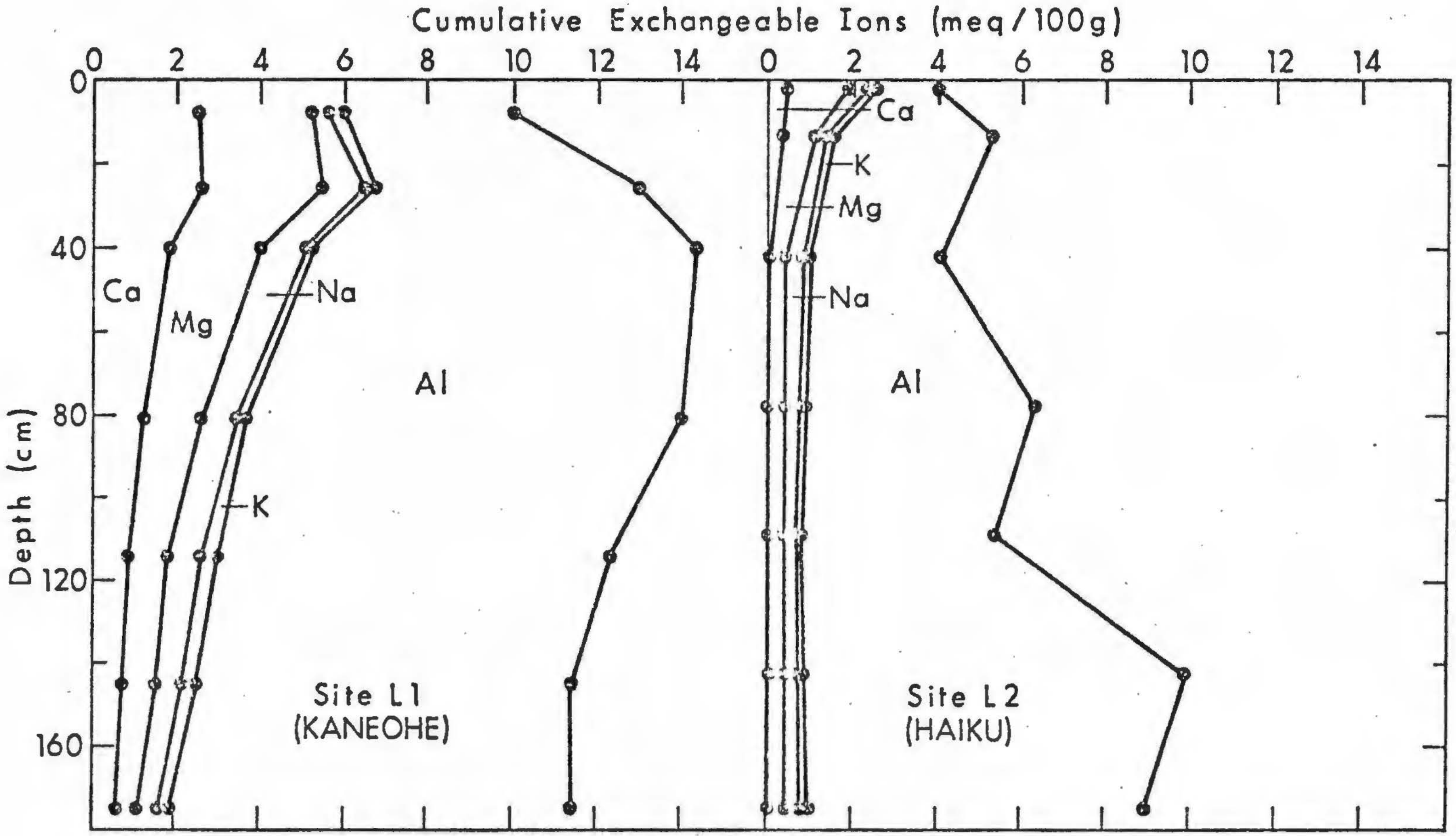


Figure 9. Cumulative distribution of exchangeable cations in the Lolekaa soils.

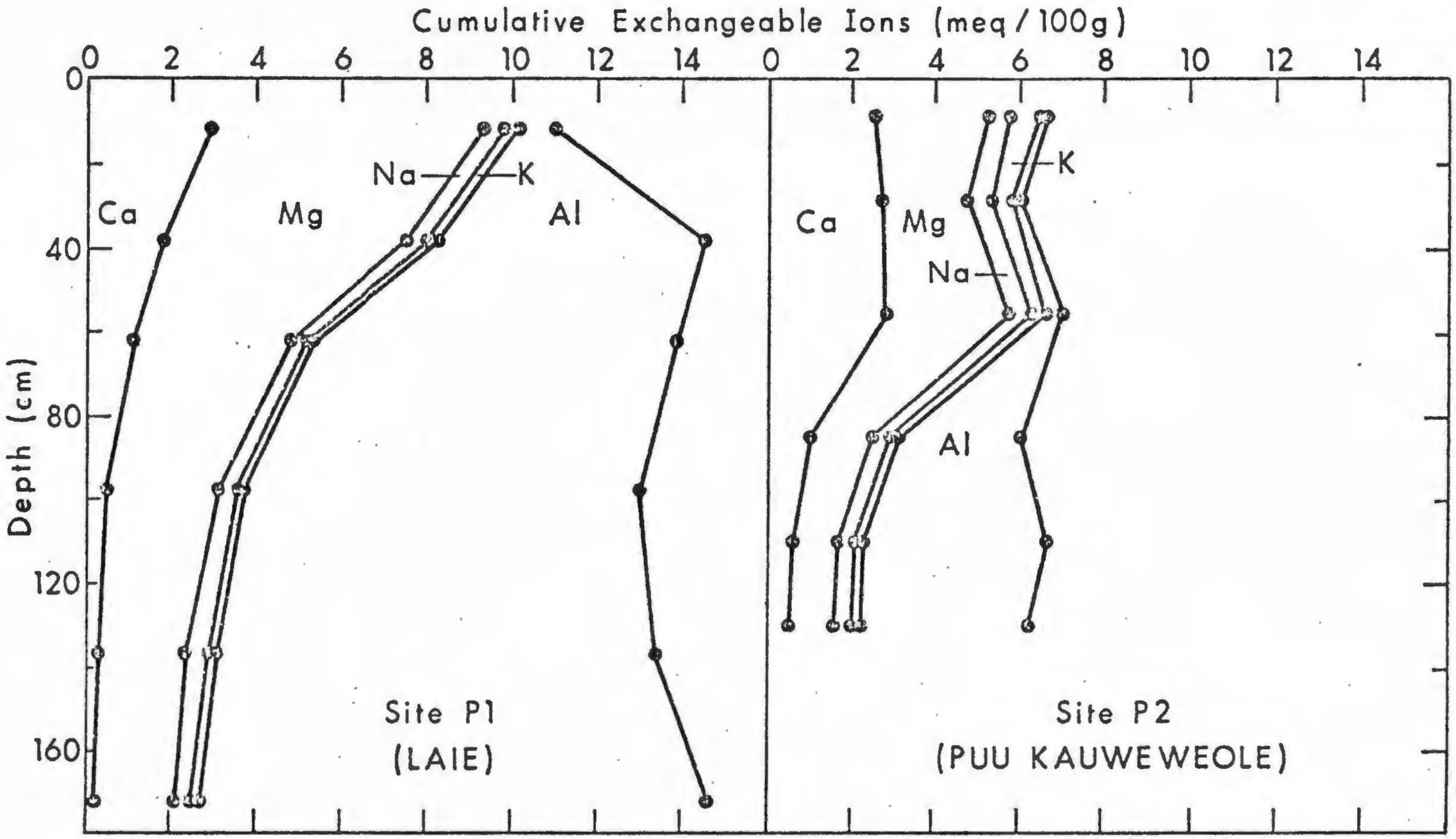


Figure 10. Cumulative distribution of exchangeable cations in the Paumalu soils.

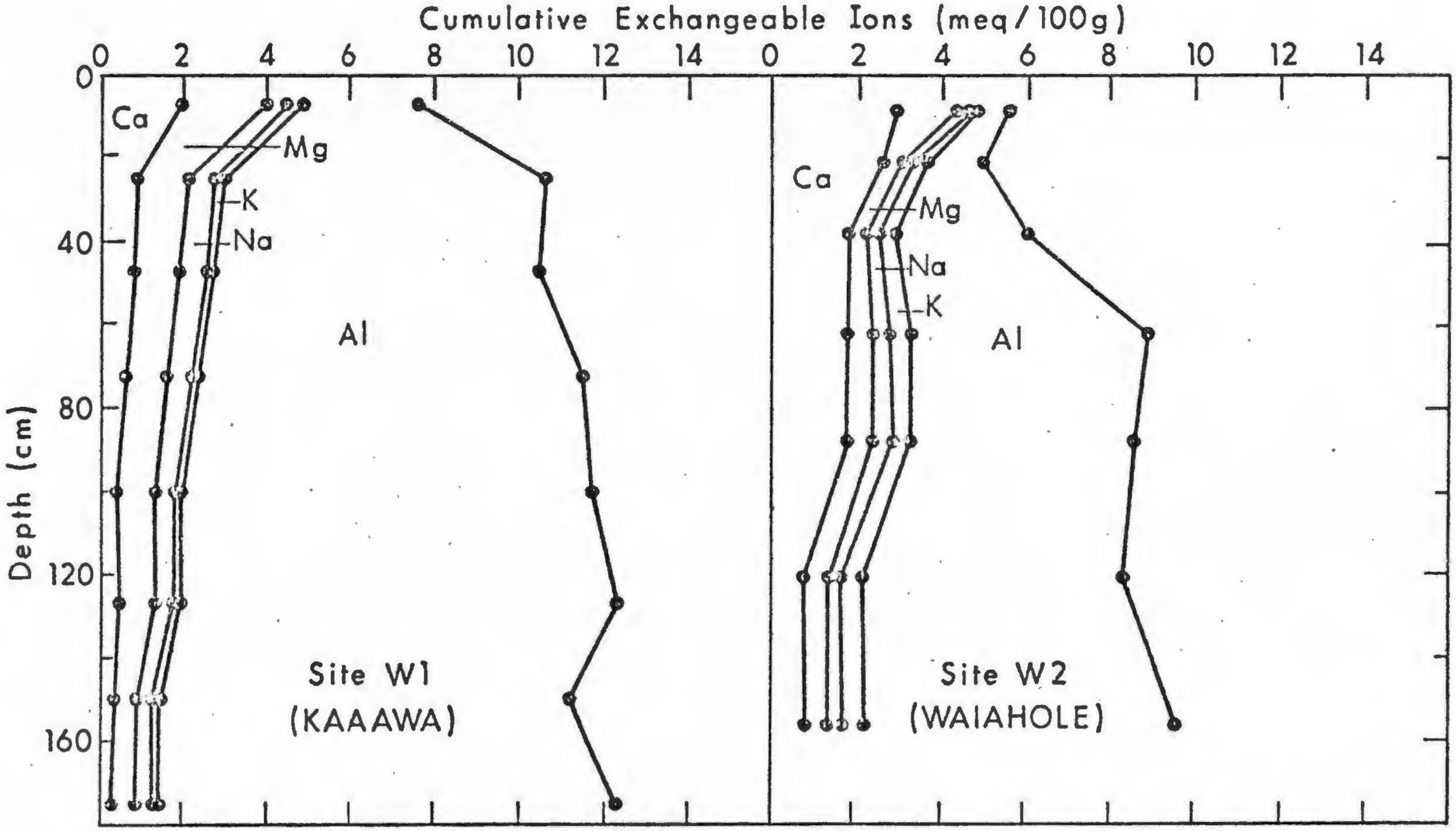


Figure 11. Cumulative distribution of exchangeable cations in the Waikane soils.

those of site 2's. Exchangeable Al also follows a similar trend. The exchangeable Al occupies a major portion of the ECEC.

The Alaeloa soils at site A1 (Koolau Boys' Home) has an unusually high exchangeable Mg (7 to 9 meq/100 g) and the percentage of Mg saturation varies from 57 to 73. Because this soil occurs in the Koolau Caldera, hydrothermal action of the ferromagnesium minerals may have been responsible for the large amounts of Mg.

The Lolekaa soil at site L2 (Haiku) has extremely low bases. The median annual rainfall at this location exceeds 2,500 mm per annum and is responsible for extreme leaching of bases. The exchangeable Ca, Mg, Na, and K are less than 0.4, 1.6, 0.5, and 0.2 meq/100 g, respectively.

Most of the soils have large proportions of exchangeable Mg (Figs. 8 through 11) indicating the advanced stage of weathering (Buol et al., 1973; Martini and Jaramillo, 1975; Saunders, 1959).

Extractable Aluminum. The carbon dioxide charged water percolating through the soil profile removes free salts and exchangeable Ca, Mg, Na, and K. Hydrogen ions adsorbed in sufficient concentration react with the clay and release Al^{3+}. The displaced Al^{3+} may enter the exchange complex or may exist as one or more of the following polymers: $Al(OH)^{2+}$, $Al(OH)_2^{+}$, $Al(OH)_3$. They can form complexes with organic matter or enter in the interlayers of crystals (McLean, 1971).

The acidic nature of the mineral soils are primarily due to the H^+ released from the hydrolysis of Al^{3+} and related compounds. Exchangeable H^+ are responsible for soil acidity in organic soils or soils with appreciable organic matter. Below pH 5.5, Al^{3+} becomes the principal cation of the exchange complex (Coleman and Thomas, 1967). Percent Al saturation associated with ECEC increases when the soil pH decreases below 5.5. Soil solution Al becomes appreciable when percent Al saturation is greater than 60% (Nye et al., 1961; Evans and Kamprath, 1970).

Reduced root growth in turn will affect the uptake of water and nutrient elements (Adams and Lund, 1966; Ragland and Coleman, 1960; Rios and Pearson, 1964). Aluminum has been found to interfere with the uptake and translocation of Ca (Evans and Kamprath, 1970; Johnson and Jackson, 1964). Aluminum in soil solution also interferes with the uptake and translocation of P (Clarkson, 1966; Foy and Brown, 1964; Wright and Donahu, 1953).

Growth of corn was reported not to be affected when Al saturation was less than 50% (Kamprath, 1970) but root growth was affected when the Al saturation exceeded this amount (Brenes and Pearson, 1973). Sorghum and sudan grass seemed to be sensitive to Al toxicity (Pearson, 1966).

Sweet potato, on the other hand, was tolerant to large amounts of exchangeable Al (Russell, 1973). Based on the performance of plantain, banana is also believed to be tolerant to high Al soils (J. M. Spain, personal communication). Crop tolerance to Al varied with species (Hewitt, 1952; Jackson, 1967) and varieties within species (Foy et al., 1967, 1973).

In organic soils or in soils with appreciable organic matter content, soil acidity is primarily attributable to exchangeable H^+ from organic matter (Kamprath, 1967). Evans and Kamprath (1970) reported that at a given soil pH, Al^{3+} in soil solution decreases with increasing amounts of organic matter. Recently, the role of organic matter in decreasing exchangeable Al was emphasized by Thomas (1975). It is believed that soil organic matter formed complexes with the Al^{3+}.

In strongly acid soils, increasing amounts of electrolytes in soil solution increase Al^{3+} in the soil solution (Brenes and Pearson, 1973; Fried and Peech, 1946). Brenes and Pearson (1973) established the relationship between electrical conductivity of the saturation extract which was highly correlated with the conductivity of the soil solution, soil pH, and the Al content in the soil solution for the Tropohumults and Eutrustox of Puerto Rico. Heavy application of fertilizers on soils with high Al might result in higher amounts of Al in soil solution. When soils have a higher pH than the zero point of charge, higher electrolyte concentrations result in higher negative charges, releasing H^+, which in turn react with $Al(OH)_3$ and release salt extractable Al^{3+} (Amedee, 1974).

In this study of the Windward Oahu Humults, the exchangeable Al contents extracted with 1N KCl were usually high and generally increased with depth (Table 3). Ultisols are usually associated with large amounts of exchangeable Al (Soil Survey Staff, 1973). The exchangeable Al varied from 0 to 12 meq/100 g in the Windward Oahu Ultisols. The Alaeloa soils and the Paumalu soil at site P2 (Puu Kauweweole) had less than 5 meq/100 g soil. The exchangeable Al contents of the Windward Oahu soils are usually higher than the Ultisols of the other parts of Hawaii (SCS, USDA et al., 1976).

For the soils studied, the pH values in 1N KCl are better indicators of exchangeable Al than pH in water (Fig. 12). Exchangeable Al becomes appreciable when soil pH in KCl is below 4.5.

A preliminary study of the Lolekaa soil at site L2 (Haiku) and the Waikane soil at site W2 (Waiahole) revealed that the dominant species of Al extracted by 1N KCl was trivalent. This fact was shown when Al determined from the KCl extract by volumetric method, colorimetry, and atomic absorption spectroscopy were nearly the same. Dalal (1975) showed that the predominant species was Al^{3+} below pH 4.5 (in 1N KCl extract)

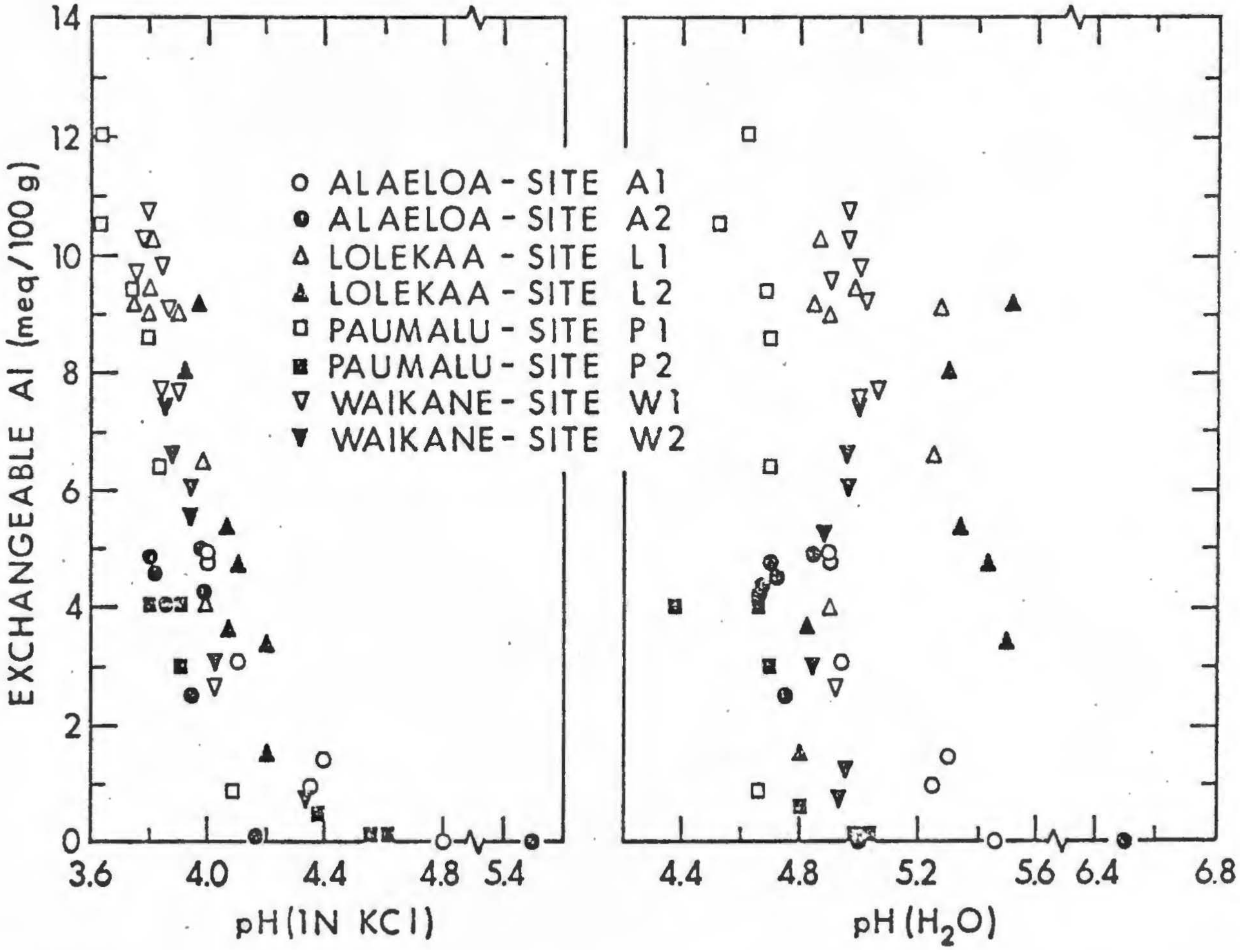


Figure 12. Relationship between soil pH and exchangeable aluminum in Windward Oahu soils.

and $Al(OH)_3$ from pH 4.5 to 6.3. The other hydrolysis products present in small amounts are the monomer species of $Al(OH)^{2+}$ and $Al(OH)_2^+$ and the polymer species $Al_6(OH)_{15}^{3+}$ or other polymers.

Percent aluminum saturation of the ECEC is an important parameter related to Al in soil solution. Percent Al saturation refers to the ratio of exchangeable Al to the ECEC expressed as a percentage.

The percent Al saturation vary from 0 to 90 for the soils in this study area. The subsoils have higher percent Al saturation values than the surface soils. Lime can be applied to reduce the surface soil Al saturation but correction in the subsoil may be a problem. The distribution of organic C, exchangeable Al and percent Al saturation with depth are shown in Figures 13 through 16.

When large amounts of liming materials are needed to raise the soil pH to a desired level, liming can be based on the reduction of percent Al saturation to a desired level for the crop in question (Reeve and Sumner, 1970a, 1970b; Kamprath, 1972). About 1.5 to 2 meq of lime will be necessary to neutralize 1 meq of Al (Kamprath, 1967).

Phosphate Adsorption. Highly weathered soils are usually deficient in P and also fix large quantities of applied P. The composition of the fine earth fractions and their relative

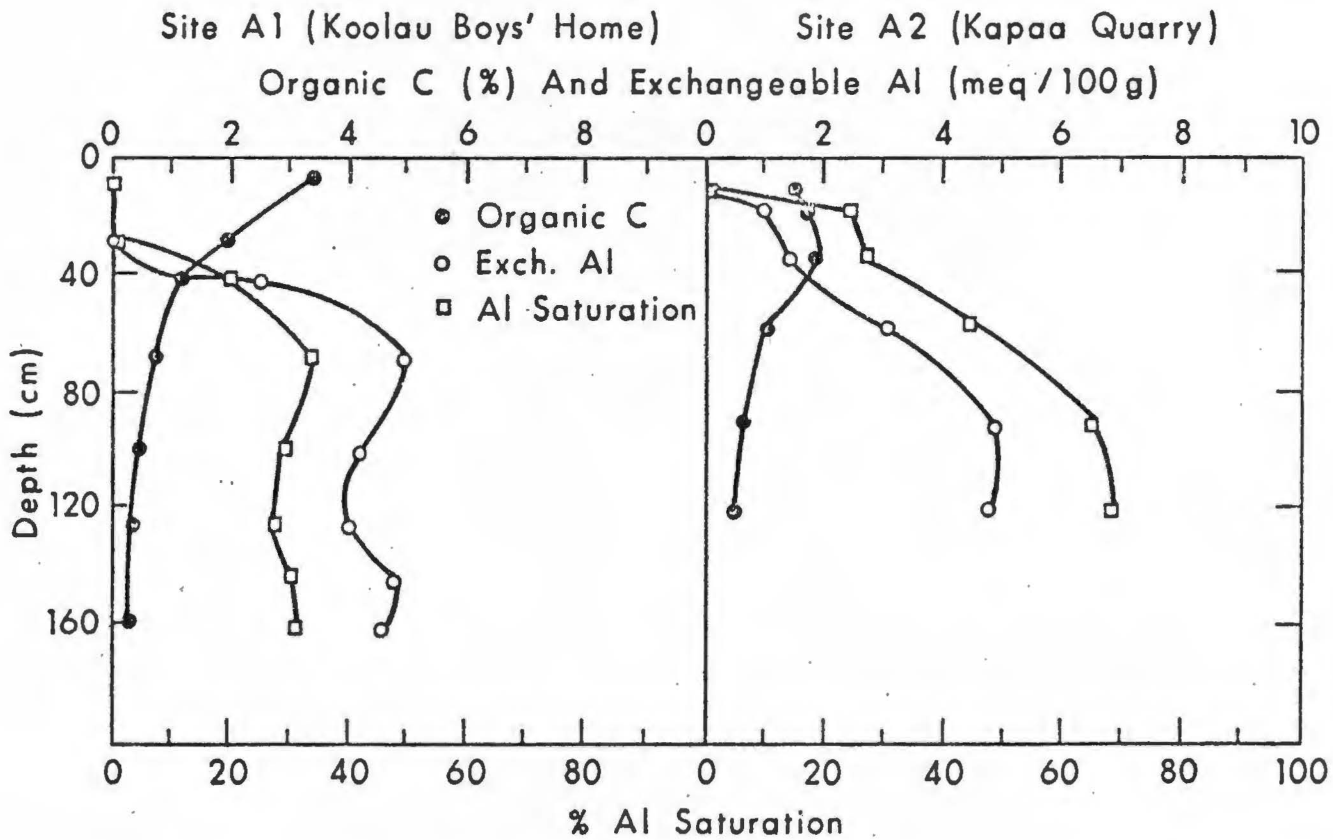


Figure 13. Relationship between organic carbon, exchangeable aluminum, and aluminum saturation in Alaeloa soils.

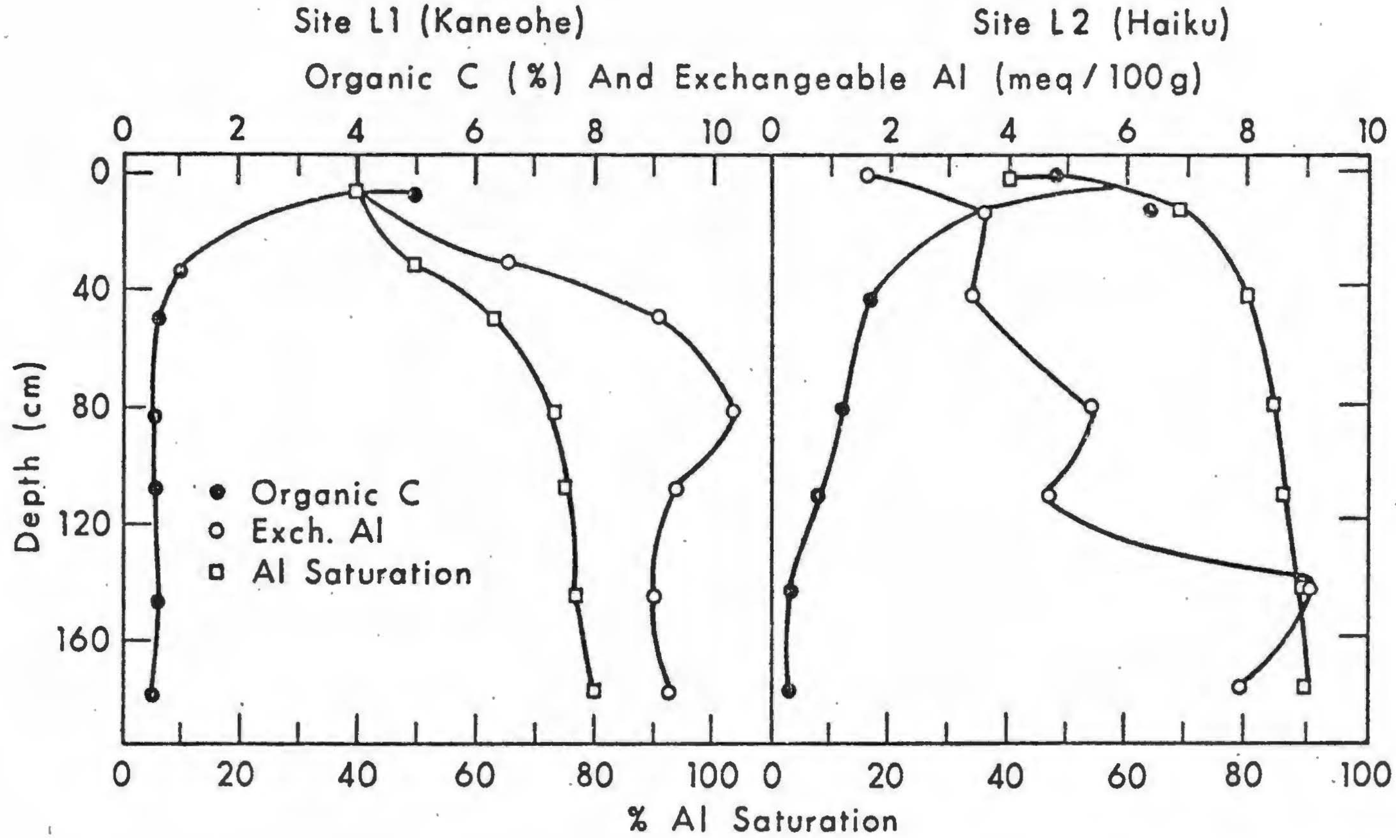


Figure 14. Relationship between organic carbon, exchangeable aluminum, and aluminum saturation in Lolekaa soils.

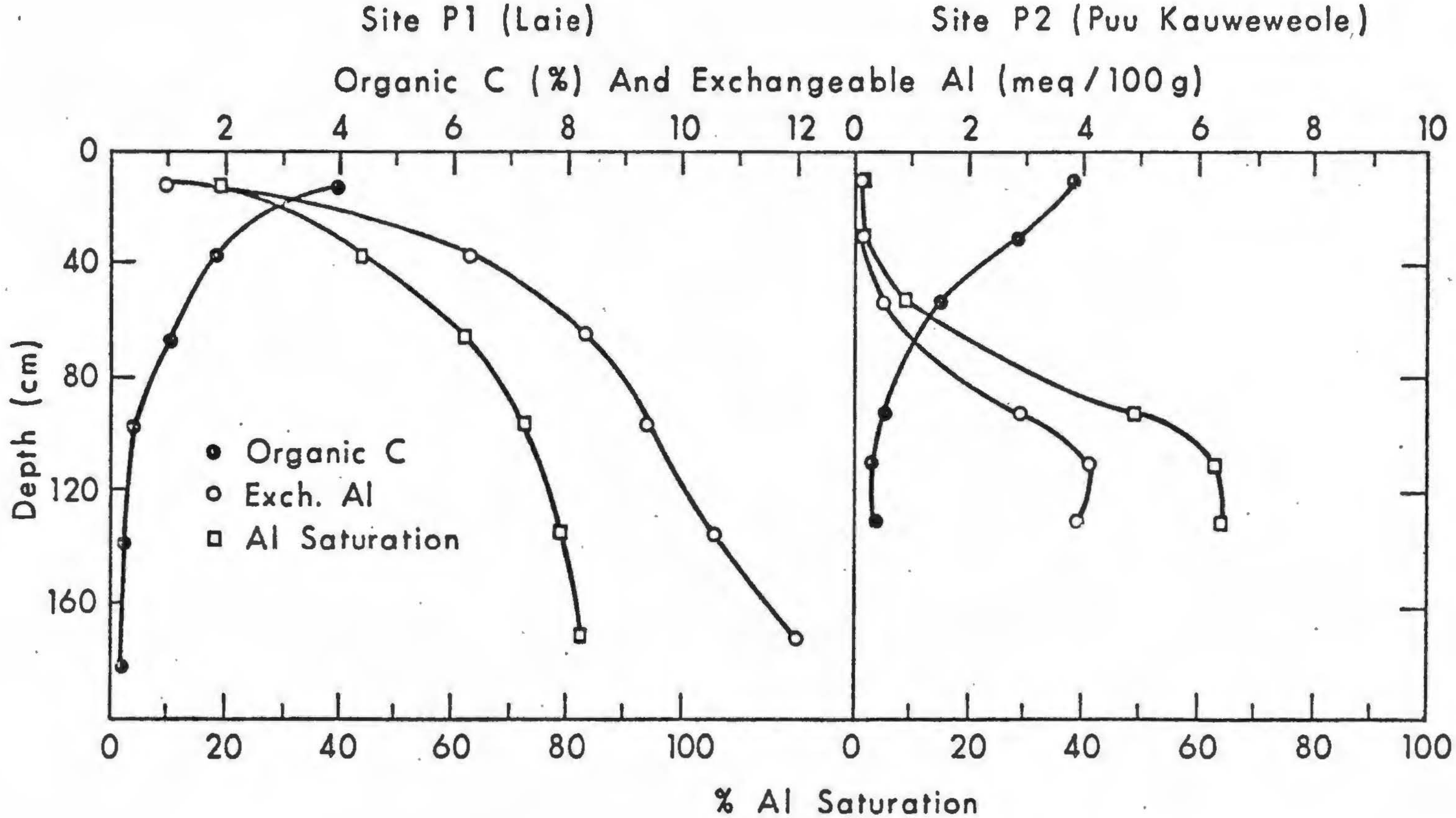


Figure 15. Relationship between organic carbon, exchangeable aluminum, and aluminum saturation in Paumalu soils.

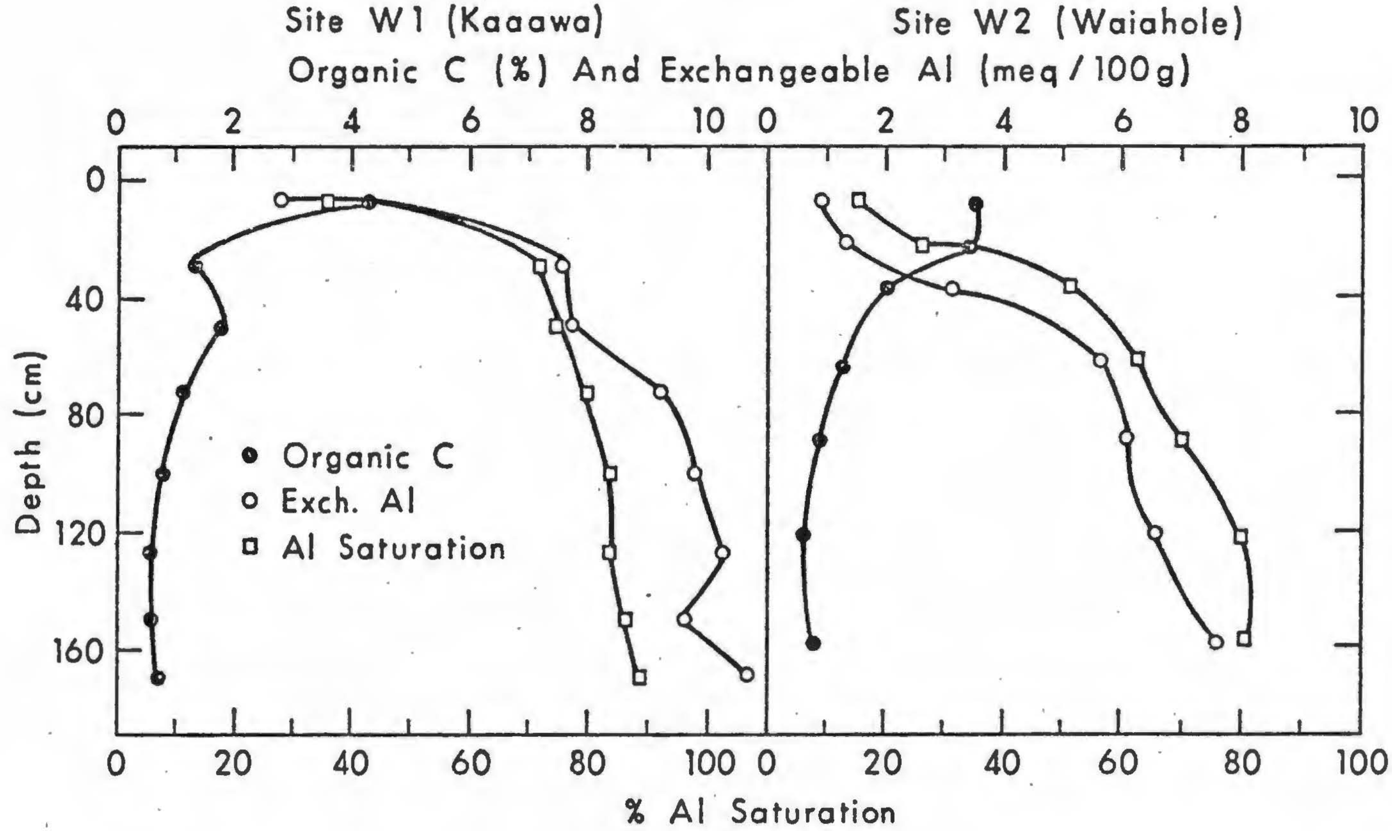


Figure 16. Relationship between organic carbon, exchangeable aluminum, and aluminum saturation in Waikane soils.

amounts influence the amounts of P fixed. The largest amounts of P is fixed by amorphous oxides followed by crystalline oxides, kaolin, and montmorillonites (Fox et al., 1968). Layered silicates such as illite, vermiculite, and kaolinite fix less P than iron and aluminum oxides (Sawhney, 1974). Gel-like coatings on silicate clays also fix P (Fox et al., 1971).

Highly leached soils are strongly acidic and possess large amounts of Al. Coleman et al. (1960) obtained the following relation between exchangeable Al and P fixed in North Carolina subsoils.

$$y = 0.077 + 0.703x$$

where y = Phosphate sorbed in millimoles/5 g soil
x = Exchangeable Al in millimoles/5 g soil

Composition of the soil solution greatly influence the nutrient uptake by plants. Soil solution P of 0.05 to 0.2 ppm are found to be optimum for most of the crops (Beckwith, 1964; Fox and Kamprath, 1970; Fox, 1974; Ozane and Shane, 1967; Singh et al., 1971). In this investigation, the amounts of P required to obtain a desired level of P in soil solution are shown as adsorption isotherms (Figs. 17 and 18). The Lolekaa soil at site L1 (Kaneohe) and the Waikane soil at site W1 (Kaaawa) fix more P than the Paumalu soil at site P2 (Puu Kauweweole) and the Alaeloa soil at site A2 (Kapaa Quarry). The increased P

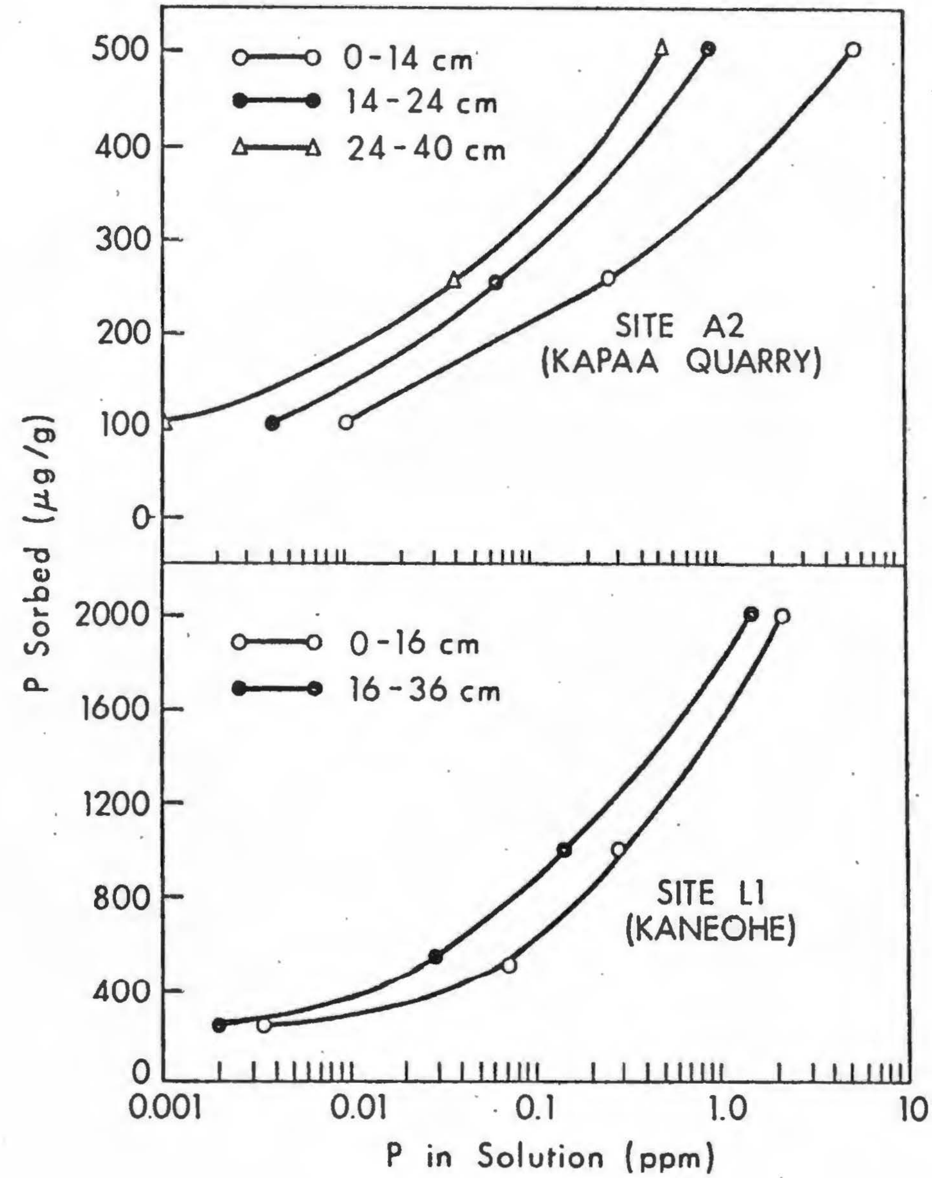


Figure 17. Phosphate sorption isotherms of Alaeloa and Lolekaa soils.

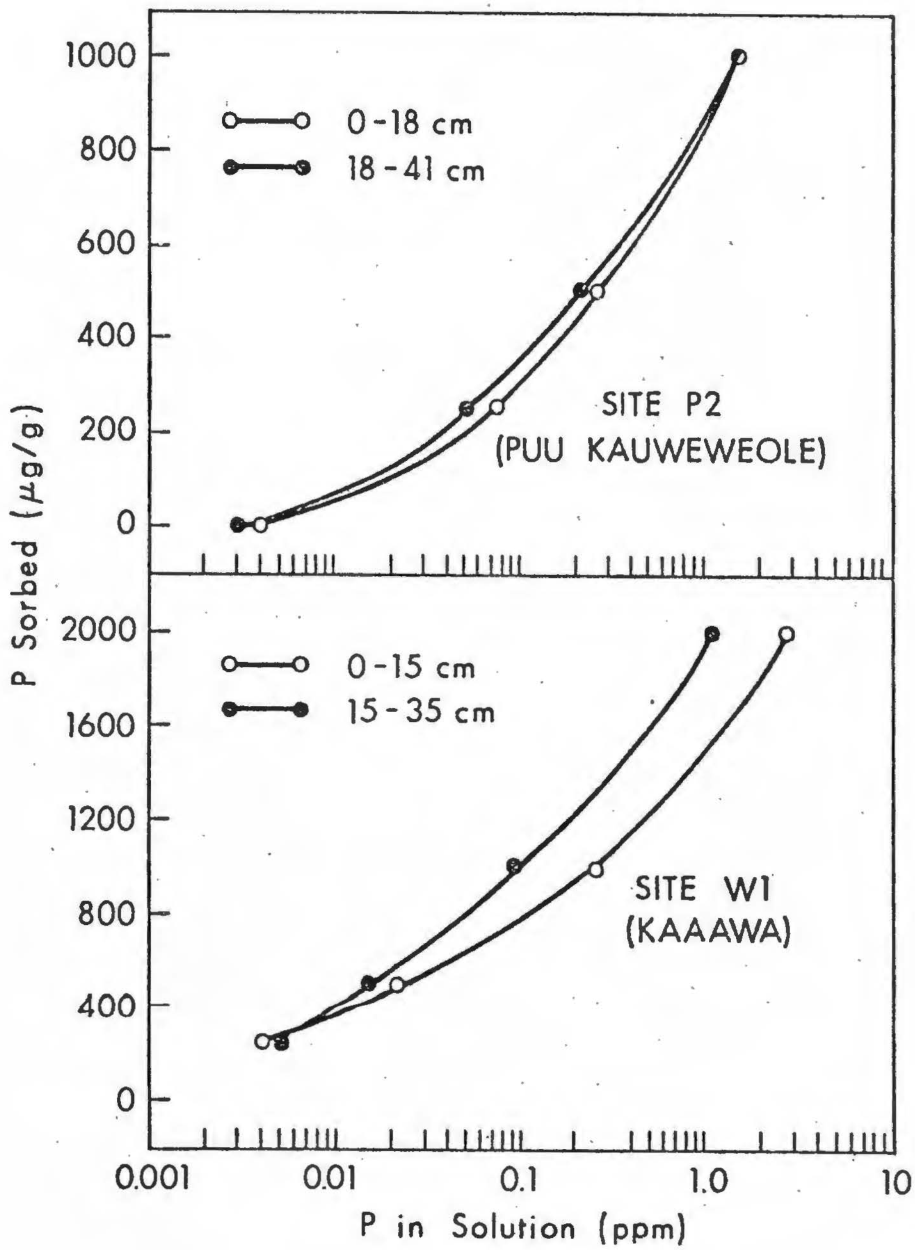


Figure 18. Phosphate sorption isotherms of Paumalu and Waikane soils.

fixation of these soils may be due to the presence of appreciable amounts of X-ray amorphous material and goethite. The subsurface soils fix larger amounts of P than the surface soils. The increased P fixation of the subsurface soils may be due to an increase in the specific surface area of the soil as evidenced by 15-bar water retention data and reduced amount of organic matter (Fox et al., 1971) and increasing amounts of exchangeable Al (Coleman et al., 1960; Syers et al., 1971; Udo and Uyu, 1972).

The data of Fox et al. (1971) show that the Paaloa and Leilehua soils (Humoxic Tropohumults) of Leeward Koolau had similar P fixing capacity to that of the Alaeloa or Paumalu soils of Windward Oahu.

According to Fox et al. (1974), sweet potato requires 0.003 ppm P in solution for 75% of maximum yield and 0.1 ppm P for 95% of maximum yield. Corn on the other hand, requires a 0.05 to 0.07 ppm P for 95% maximum yield in various soils of Hawaii.

The amount of P required to obtain 0.05 ppm in solution to a depth of 15 cm/hectare for the Alaeloa, Lolekaa, Paumalu and Waikane soils are 350, 633, 390, and 982 kg, respectively (Table 4).

Thus, for maximum crop yields, large amounts of P must be applied on the Ultisols studied. Massive application of P is known to have residual efficiency over a period of many years (Fox et al., 1974).

Table 4. Some of the Soil Properties Related to P fixation in the Humults of Windward Oahu

Soil	Depth	P for 0.05 ppm	P for 0.05 ppm of top 15 cm	15-bar Water	Clay	Organic Carbon	Exch. Al	Clay Mineralogy					
								Kaolin	2:1 Int. Grade	Mica	Goethite	Hematite	X-ray Amor.
	cm	$\mu g/g$	kg/ha	%	%	%	meq/100 g						
Alaeloa Site A2	0 - 14	160	350	14	34	1.5	0.0	4X	tr	1X	1X	1X	1X
(Kapaa Quarry)	14 - 24	230		19	39	1.7	0.9	4X	1X	tr	2X	1X	1X
	24 - 40	270		29	67	1.8	1.4	4X	tr	tr	2X	1X	1X
Lolekaa Site L1	0 - 16	440	633	33	68	4.5	3.9	2X	1X		2X	1X	2X
(Kaneohe)	16 - 36	680		34	62	1.0	6.5	2X	1X		2X	1X	2X
Paumalu Site P2	0 - 18	200	390	26	51	3.8	0.1	3X	tr	1X	1X	1X	1X
(Puu Kauweweole)	18 - 41	240		27	51	2.8	0.1	3X	1X		1X	1X	1X
Waikane Site W1	0 - 15	630	482	32	65	2.7	2.7	3X		tr	1X	1X	1X
(Kaaawa)	15 - 35	820		45	67	1.3	7.5	4X			2X	1X	2X

tr = trace; 1X = Less than 10%; 2X = 10 to 30%; 3X = 30 to 60%; 4X = Greater than 60%.

Mineralogical Properties

The mineralogical composition of clay, silt, and sand-size fractions are presented in Table 5. The X-ray diffractograms of selected horizons (K-saturated, air-dried, or untreated samples) from each of the control section are shown in Figures 19 through 22. All of the soils have small to trace amounts of mica or some 2:1 intergrade minerals in the clay fractions. Mica seems to be the precursor of the 2:1 intergrade minerals. The presence of mica, quartz, and 2:1 to 2:2 intergrades have been reported by Juang and Uehara (1968) on the south slope of the Koolau Range.

The clay fraction of the Alaeloa soil at site A1 (Koolau Boys' Home) is predominantly kaolinite with some amorphous materials. The silt and sand fractions have appreciable amounts of quartz, cristobalite, and hematite.

The clay fraction of the Alaeloa soil at site A2 (Kapaa Quarry) has large amounts of kaolinite, moderate amounts of goethite, and small amounts of amorphous materials. The coarse fractions have large amounts of quartz and small amounts of kaolinite, hematite, and magnetite.

The clay fraction of the Lolekaa soil at site L1 (Kaneohe) has appreciable amounts of hydrated halloysite, goethite, and amorphous materials. Small amounts of hematite and magnetites are also present. The silt and sand fractions have moderate amounts of goethite, small amounts of hydrated halloysite

Table 5. Mineralogical Composition of Sand, Silt, and Clay-Size Fraction as Determined by X-ray Diffraction Analysis*

Depth cm	2:1 Intergrade			Mica			Kaolinite			Hydrated Halloysite			Goethite			Hematite			Magnetite			Ilmenite			Quartz			Cristobalite			Gibbsite			X-ray Amorphous		
	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C	S	Si	C
Alaeloa - Site A1 (Kooiau Boys' Home)																																				
0- 18	-	-	1X	-	-	-	-	1X	4X	-	-	-	-	-	tr	-	tr	1X	-	-	-	-	-	-	3X	2X	tr	-	1X	tr	-	-	-	-	-	1X
18- 30	-	-	1X	-	-	-	-	2X	4X	-	-	-	-	-	tr	-	tr	1X	-	-	-	-	-	-	3X	2X	tr	-	1X	tr	-	-	-	-	-	1X
30- 52	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	tr	-	tr	1X	-	-	-	-	-	-	4X	2X	-	-	tr	tr	-	-	-	-	-	1X
52- 85	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	tr	-	tr	tr	-	-	-	-	-	-	4X	1X	-	-	tr	tr	-	-	-	-	-	1X
85-115	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	tr	-	tr	tr	-	-	-	-	-	-	4X	1X	-	-	tr	tr	-	-	-	-	-	1X
115-135	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	tr	-	tr	tr	-	-	-	-	-	-	4X	1X	-	-	tr	tr	-	-	-	-	-	1X
135-150	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	1X	-	tr	tr	-	-	-	-	-	-	4X	1X	-	-	1X	tr	-	-	-	-	-	1X
150-170	-	-	1X	-	-	-	tr	2X	4X	-	-	-	-	-	tr	-	tr	1X	-	-	-	-	-	-	4X	1X	-	-	tr	tr	-	-	-	-	-	1X
Alaeloa - Site A2 (Kapaa Quarry)																																				
0- 14	-	-	tr	-	-	1X	tr	1X	4X	-	-	-	-	-	1X	-	1X	1X	-	1X	-	-	-	-	4X	3X	1X	-	-	-	-	-	-	-	1X	1X
14- 24	-	-	1X	-	-	1X	tr	1X	4X	-	-	-	-	-	2X	-	1X	1X	-	1X	-	-	-	-	4X	3X	tr	-	-	-	-	-	-	-	1X	1X
24- 40	-	-	tr	-	-	tr	tr	2X	4X	-	-	-	-	-	2X	-	1X	1X	-	1X	-	-	-	-	4X	2X	-	-	-	-	-	-	-	-	1X	1X
40- 75	-	-	tr	-	-	tr	tr	2X	4X	-	-	-	-	-	2X	-	1X	1X	-	1X	-	-	-	-	4X	2X	-	-	-	-	-	-	-	-	1X	1X
75-103	-	-	tr	-	-	tr	tr	2X	4X	-	-	-	-	-	2X	-	1X	1X	-	tr	-	-	-	-	3X	2X	-	-	-	-	-	-	-	-	1X	1X
103-135	-	-	tr	-	-	tr	tr	3X	4X	-	-	-	-	-	1X	-	1X	1X	-	tr	-	-	-	-	3X	1X	-	-	-	-	-	-	-	-	1X	1X
Lolekaa - Site L1 (Kaneohe)																																				
0- 16	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	2X	1X	tr	1X	-	tr	1X	-	-	1X	-	-	-	-	-	-	-	2X	1X	2X
16- 36	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	1X	1X	tr	1X	-	tr	tr	-	-	1X	-	-	-	-	-	-	-	2X	1X	2X
36- 63	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	1X	1X	1X	1X	tr	1X	-	tr	tr	-	-	tr	-	-	-	-	-	-	-	2X	1X	2X
63- 99	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	1X	1X	tr	1X	-	tr	tr	-	-	tr	-	-	-	-	-	-	-	2X	1X	2X
99-130	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	1X	1X	tr	1X	-	tr	tr	-	-	tr	-	-	-	-	-	-	-	2X	1X	2X
130-160	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	1X	1X	tr	1X	-	tr	tr	-	-	tr	-	-	-	-	-	-	-	2X	1X	2X
160-190	-	-	1X	-	-	-	-	-	-	1X	1X	2X	1X	2X	2X	1X	1X	1X	tr	1X	-	tr	tr	-	-	tr	-	-	-	-	-	-	-	2X	1X	2X
Lolekaa - Site L2 (Haiku)																																				
0- 4	-	-	1X	-	-	-	tr	tr	-	tr	tr	2X	1X	1X	2X	1X	tr	1X	1X	tr	-	-	tr	-	-	tr	-	-	-	-	tr	1X	-	-	-	2X
4- 23	-	-	1X	-	-	-	-	tr	-	-	tr	2X	1X	1X	2X	1X	tr	1X	1X	1X	-	-	tr	-	-	tr	-	-	-	-	tr	1X	-	-	-	2X
23- 62	-	-	-	-	-	-	-	tr	-	-	tr	2X	1X	1X	2X	1X	tr	1X	1X	1X	-	-	tr	-	-	tr	-	-	-	-	tr	1X	-	-	-	2X
62- 94	-	-	-	-	-	-	-	tr	-	-	tr	2X	1X	1X	2X	1X	tr	1X	1X	1X	-	-	tr	-	-	tr	-	-	-	-	tr	1X	-	-	-	2X
94-125	-	-	-	-	-	-	-	1X	-	-	1X	2X	1X	1X	2X	1X	tr	1X	1X	tr	-	-	tr	-	-	tr	-	-	-	-	-	1X	-	-	-	2X
125-160	-	-	-	-	-	-	-	1X	-	-	1X	2X	1X	1X	2X	1X	tr	1X	1X	tr	-	-	tr	-	-	tr	-	-	-	-	-	1X	-	-	-	2X
160-190	-	-	-	-	-	-	tr	1X	-	tr	1X	2X	1X	1X	2X	1X	tr	1X	1X	tr	-	tr	tr	-	-	tr	-	-	-	-	-	1X	-	-	-	2X
Paumalu - Site P1 (Laie)																																				
0- 24	-	-	tr	-	-	1X	tr	tr	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	2X	-	tr	1X	1X	-	-	-	-	tr	1X	-	-	1X
24- 52	-	-	1X	-	-	-	tr	1X	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	1X	-	tr	tr	-	-	-	-	-	tr	tr	-	-	1X
52- 78	-	-	1X	-	-	-	tr	1X	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	1X	-	-	tr	-	-	-	-	-	tr	tr	-	-	1X
78-117	-	-	1X	-	-	-	tr	1X	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	1X	-	-	tr	-	-	-	-	-	tr	tr	-	-	1X
117-155	-	-	1X	-	-	-	tr	1X	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	1X	-	-	tr	-	-	-	-	tr	tr	tr	-	-	1X
155-190	-	-	1X	-	-	-	tr	1X	3X	-	-	-	1X	1X	1X	1X	2X	1X	1X	1X	-	1X	1X	-	-	tr	-	-	-	-	-	tr	tr	-	-	1X
Paumalu - Site P2 (Puu Kauweweole)																																				
0- 18	-	-	tr	-	-	1X	tr	tr	2X	-	-	-	1X	1X	2X	1X	2X	1X	tr	tr	-	-	2X	-	tr	1X	-	-	-	-	1X	1X	1X	-	-	1X
18- 41	-	-	tr	-	-	1X	tr	tr	2X	-	-	-	1X	1X	2X	1X	2X	1X	tr	tr	-	-	1X	-	tr	1X	-	-	-	-	tr	1X	1X	-	-	1X
41- 72	-	-	tr	-	-	-	tr	1X	3X	-	-	-	2X	2X	1X	2X	1X	1X	tr	tr	-	-	1X	-	tr	tr	-	-	-	-	1X	tr	1X	-	-	1X
72-100	-	-	tr	-	-	-	tr	1X	3X	-	-	-	1X	2X	1X	1X	2X	1X	tr	tr	-	-	1X	-	tr	tr	-	-	-	-	1X	tr	1X	-	-	1X
100-120	-	-	tr	-	-	-	tr	1X	3X	-	-	-	1X	2X	1X	1X	1X	1X	tr	tr	-	-	1X	-	tr	-	-	-	-	-	tr	tr	1X	-	-	1X
120-140	-	-	tr	-	-	-	tr	1X	3X	-	-	-	1X	2X	1X	1X	1X	1X	tr	tr	-	-	1X	-	tr	-	-	-	-	-	1X	tr	1X	-	-	1X
Waikane - Site W1 (Kaaawa)																																				
0- 15	-	-	-	-	-	tr	-	-	-	2X	1X	3X	2X	2X	1X	1X	1X	1X	2X	2X	-	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	2X
15- 35	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	2X	1X	1X	1X	1X	1X	-	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	2X
35- 60	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	2X	-	1X	1X	1X	1X	1X	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	1X
60- 85	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	2X	-	1X	1X	1X	1X	1X	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	1X
85-115	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	2X	-	1X	1X	1X	1X	1X	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	1X
115-140	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	1X	-	1X	tr	1X	1X	tr	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	1X
140-160	-	-	-	-	-	-	-	-	-	1X	2X	4X	2X	2X	1X	-	1X	tr	1X	1X	tr	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	1X
160-190	-	-	-	-	-	-	-	-	-	1X	2X	3X	2X	2X	1X	-	1X	1X	1X	1X	tr	-	tr	tr	-	-	-	-	-	-	-	-	-	-	-	tr
Waikane - Site W2 (Waiahole)																																				
0- 16	-	-	tr	-	-	-	-	-	-	tr	tr	1X	2X	2X	2X	1X	2X	1X	tr	tr	-	-	2X	-	-	1X	1X	-	-	-	tr	1X	-	-	-	2X
16- 28	-	-	-	-	-	-	-	-	-	tr	tr	1X	2X	2X	2X	1X	2X	tr	tr	tr	-	-	2X	-	-	1X	1X	-	-	-	tr	1X	-	-	-	2X
28- 46	-	-	-	-	-	-	-	-	-	tr	1X	1X	2X	2X	3X	1X	1X	1X	tr	-	-	-	1X	-	-	1X	1X	-	-	-	tr	1X	-	-	-	2X
46- 76	-	-	-	-	-	-	-	-	-	1X	1X	1X	2X	2X	3X	1X	1X	1X	tr	tr	-	-	1X	-	-	-	-	-	-	-	1X	1X	-	-	-	2X
76- 99	-	-	-	-	-	-	-	-	-	1X	1X	2X	2X	2X	2X	1X	1X	tr	tr	tr	-	-	1X	-	-	-	-	-	-	-	1X	1X	-	-	-	2X
99-142	-	-	tr	-	-	-	-	-	-	1X	1X	2X	2X	2X	2X	1X	2X	1X	tr	1X	-	-	1X	-	-	-	-	-	-	-	1X	1X	-	-	-	2X
142-168	-	-	tr	-	-	-	-	-	-	1X	1X	3X	2X	2X	2X	1X	2X	1X	tr	1X	-	-	1X	-	-	-	-	-	-	-	tr	tr	-	-	-	1X

*S - Sand; Si - Silt; C - Clay. 1X - Less than 10%; 2X - 10 - 30%; 3X - 30 - 60%; 4X - Greater than 60%; tr - trace.

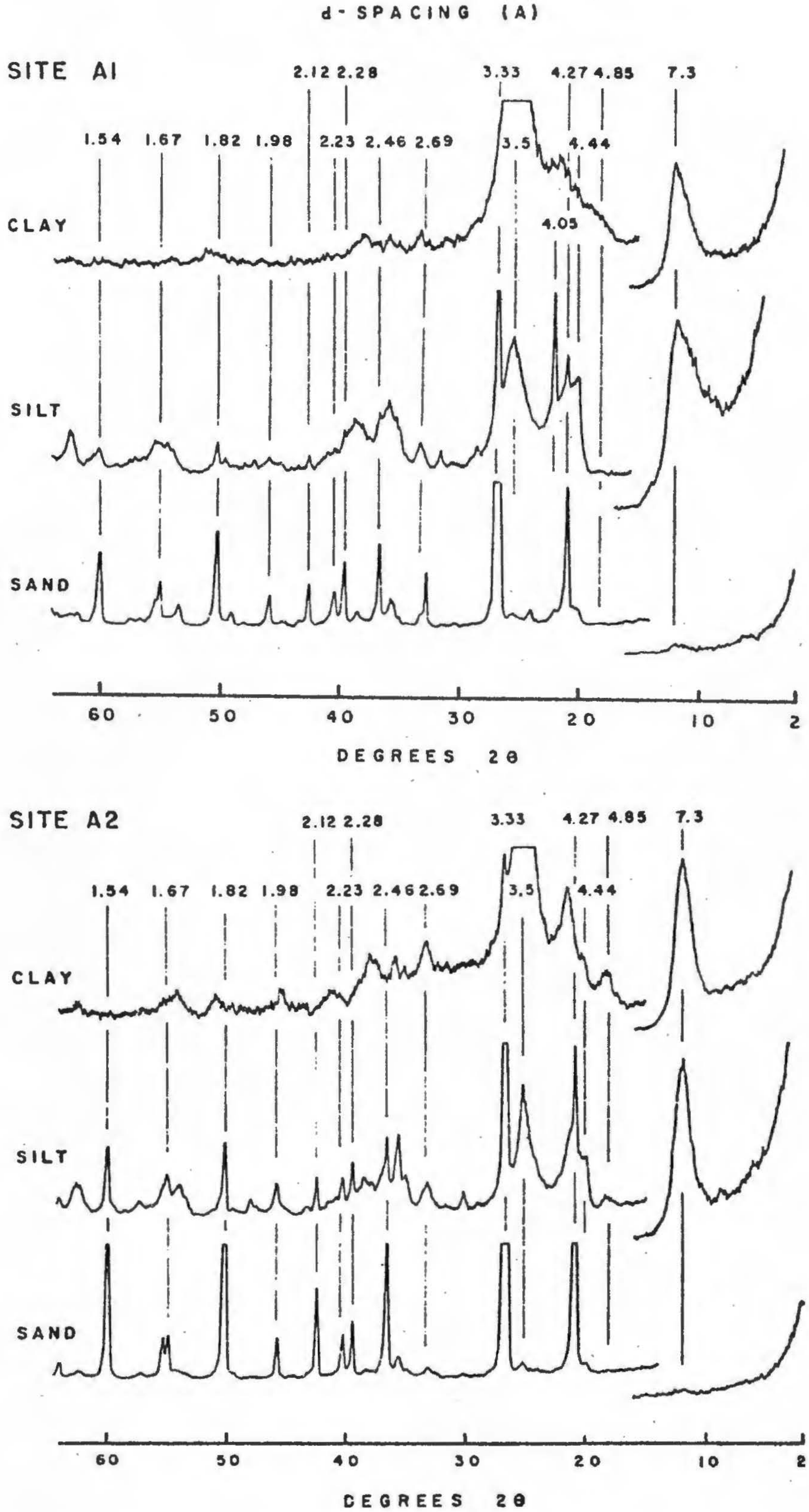


Figure 19. X-ray diffraction patterns of the clay, silt, and sand-size fractions in the B22 horizon (30-52 cm) from Site A1 and B21 horizon (24-40 cm) from Site A2 of Alaeloa soils.

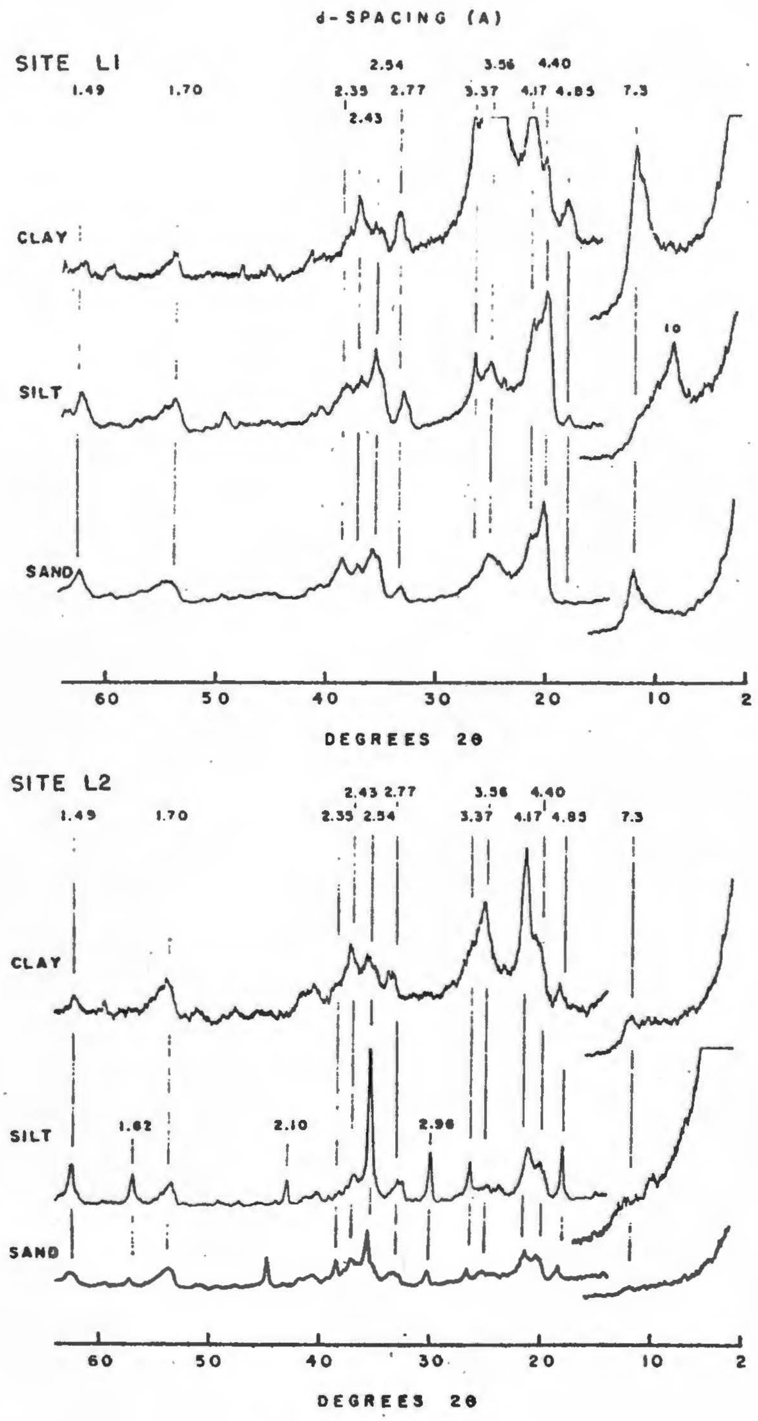


Figure 20. X-ray diffraction patterns of the clay, silt, and sand-size fractions in the B22 horizon (36-63 cm) from Site L1 and B21 horizon (23-62 cm) from Site L2 of Lolekaa soils.

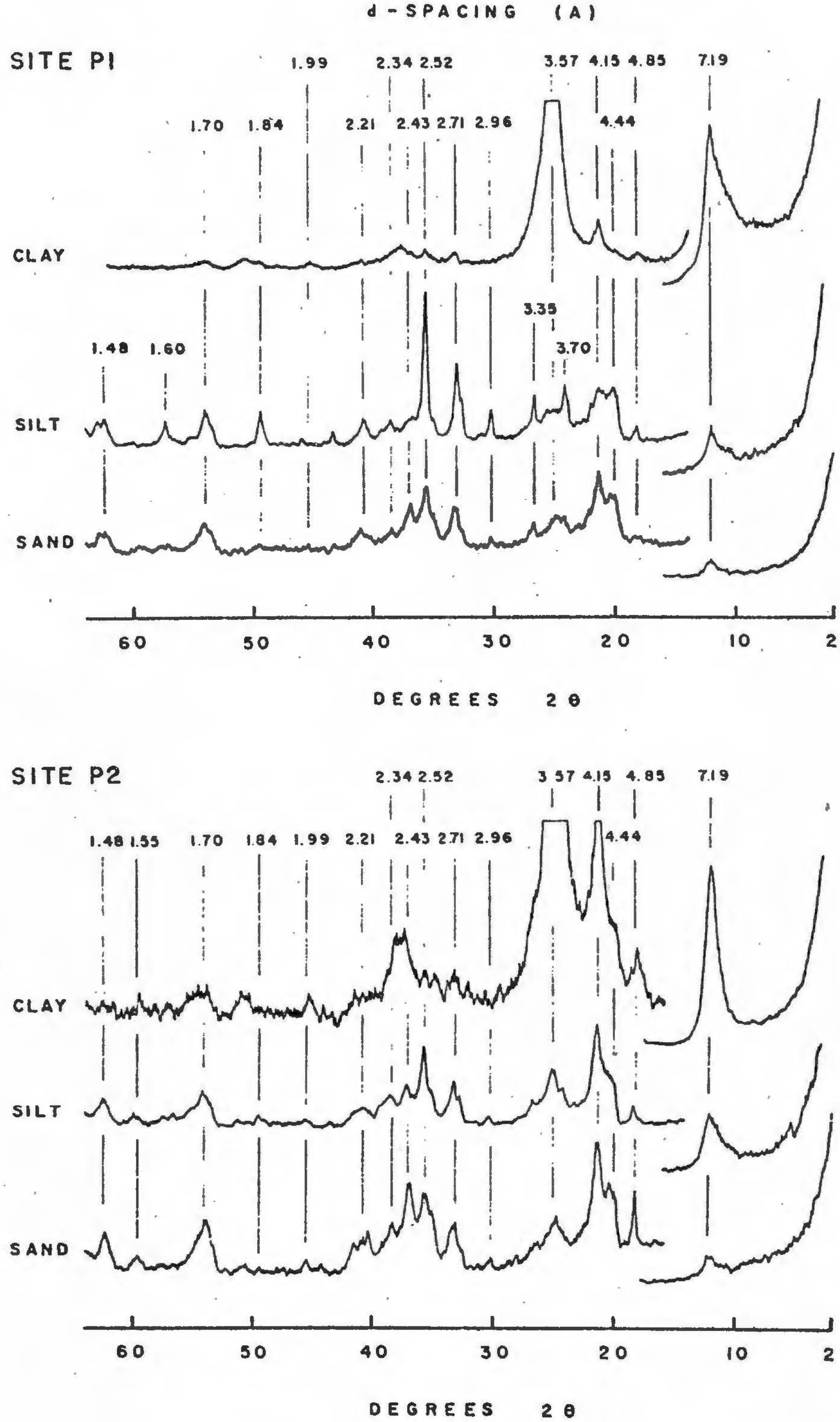


Figure 21. X-ray diffraction patterns of the clay, silt, and sand-size fractions in the B21 horizon (24-52 cm) from Site P1 and B21 horizon (41-72 cm) from Site P2 of Paumalu soils.

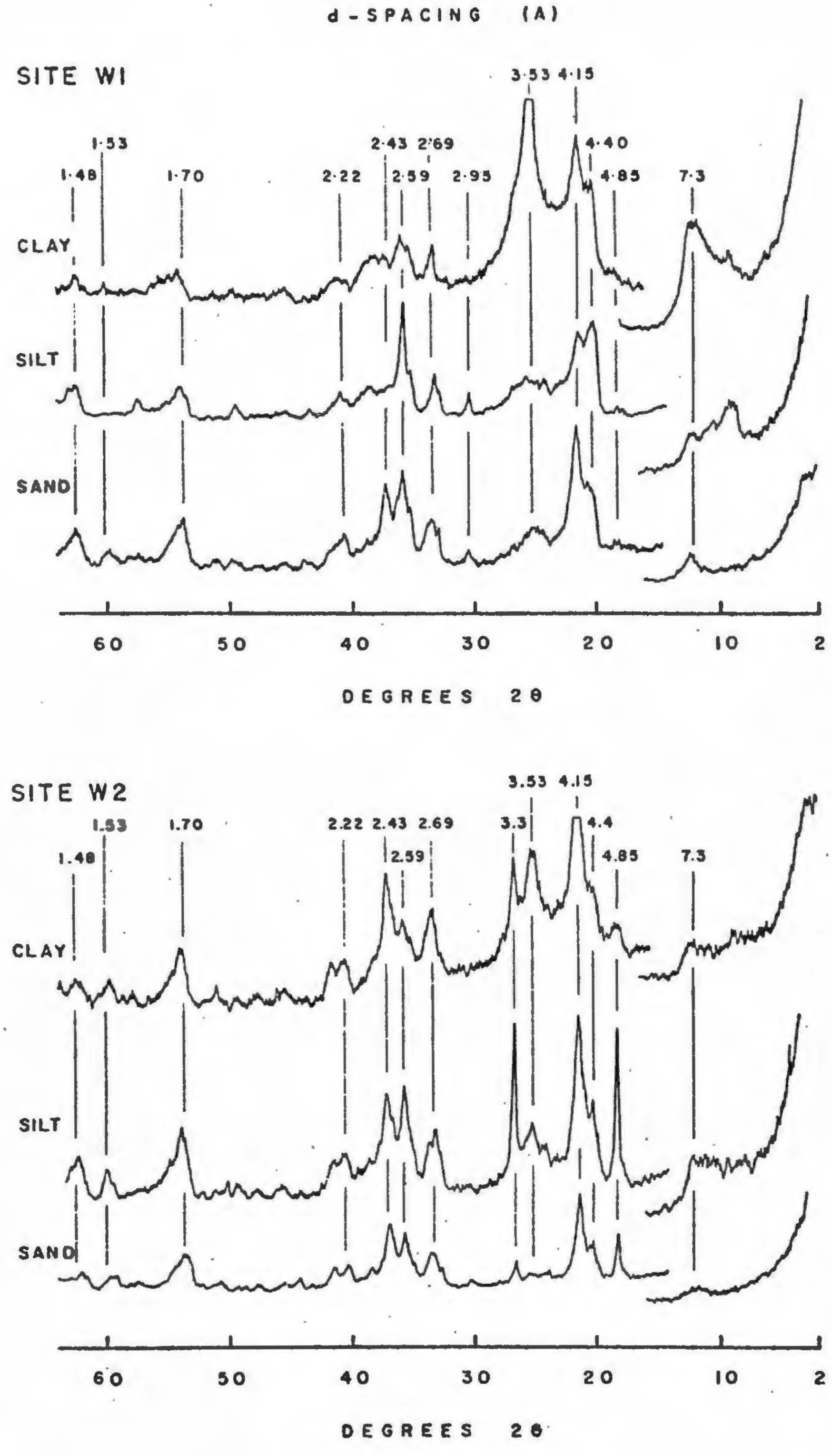


Figure 22. X-ray diffraction patterns of the clay, silt, and sand-size fractions in the B22 horizon (35-60 cm) from Site W1 and B22 horizon (28-46 cm) from Site W2 of Waikane soils.

and hematite.

The mineralogy of the Lolekaa soil at site L2 (Haiku) is more or less similar to that of the other Lolekaa soil. The coarse fractions of this soil contain some gibbsite but lesser amounts of hematite.

The clay fraction of the Paumalu soil at site P1 (Laie) has moderate amounts of kaolin and small amounts of goethite and hematite. The silt and sand fractions consist of kaolin, goethite, hematite, magnetite, and ilmenite.

The mineralogy of the Paumalu soil at site P2 (Puu Kauweweole) is similar to that of the other Paumalu soil except that the kaolin may be primarily halloysite.

The dominant clay mineral in the Waikane soil at site W1 (Kaaawa) is kaolinite with goethite, hematite, and amorphous materials. The coarse fraction consists of halloysite, goethite, and some hematite, magnetite, and amorphous materials.

The Waikane soil at site W2 (Waiahole) has less hydrated halloysite and more goethite and amorphous materials than the clay fraction of the other Waikane soil. The coarse fractions of this soil has some gibbsite.

There are little or no weatherable minerals in the coarse fractions of these soils and these soils thus have low potential to release plant nutrients. The mineralogy of the silt and sand-size fractions are similar to that of the clay fraction except in the

Alaeloa soils which have quartz in the coarse fractions. The high cation exchange capacity in many of the soils are due to the presence of amorphous materials and mica or the 2:1 intergrades. Amorphous materials also contribute to low bulk density values and to the high phosphate fixation. Post erosional volcanic activity might have contributed to the appreciable amounts of amorphous materials in the Lolekaa and Waikane soils.

The weathering of clay-size micas and 2:1 intergrades releases K. The rate of K release depends upon the amount, stability, and weathering stage of the micaceous minerals.

Macdonald and Abbott (1970) reported that hydrothermal activity in and around the Koolau Caldera had resulted in the alteration of pyroxene into chlorites and quartz. The quartz in the silt and sand-size fractions in the Alaeloa soils are believed to be of hydrothermal origin.

Landscape Parameters

The landscape parameters, viz., physiography, parent material, elevation, slope, drainage, permeability, rainfall, and temperature of the soils of the Windward Oahu study area are summarized in Table 6.

The Alaeloa soils occur in fairly low rainfall areas. The soil moisture regime ranges from ustic to udic and may require supplemental irrigation, especially for long duration crops.

Table 6. Landscape Parameters of the Humults of Windward Oahu

Series	Physiography	Parent Material	Elevation	Slope	Drainage	Permeability	Annual Rainfall	Mean Annual Temp.
			m	%			mm	C
Alaeloa	Moderately steep to steep uplands	Basic igneous rocks	30-330	3-70	Well-drained	Moderately rapid	890-1525	22.2
Lolekaa	Nearly level to gently sloping terraces and moderately sloping to very steep fans	Old gravelly alluvium and colluvium of basic igneous rocks	0-160	3-70	Well-drained	Moderately rapid	1780-2290	22.5
Paumalu	Gently sloping to very steep uplands	Old gravelly alluvium and colluvium of basic igneous rocks	230-330	3-70	Well-drained	Moderately rapid	1270-1780	22.2
Waikane	Gently sloping to very steep alluvial fans and terraces	Alluvium and colluvium of basic igneous rocks	60-330	3-70	Well-drained	Moderately rapid	1270-1780	22.2

Source: Foote et al. (1972)

The Lolekaa, Paumalu, and Waikane series have udic moisture regime. In these soils, rainfall is well distributed throughout the year (Figs. 4 and 5) and the moisture regime is favorable for crop production.

All four soil series have isohyperthermic temperature regime, moderately rapid permeability, and good drainage. All of these soil properties are favorable for agricultural or engineering uses.

Slope is one of the dominant landscape parameters that influences the use of Humults in Hawaii, in particular, the Windward Oahu. These Humults occur on varying slopes as steep as 70%; their extent in the various slope categories are presented in Table 7. In general, most of these soils occur on slopes above 20%.

Slope characteristics, such as shape, length, direction, and pattern, determine the rate and amount of run off, erodability of the soil and the usability of agricultural machinery. According to Sahara et al. (1972), soils with slopes of less than 10% will have minimum difficulty in machine usage. Soils with slopes of 11 to 20% will have increasing difficulty in their usage. Land clearing machinery can be efficiently used on slopes as steep as 35%. Incidences of landslides are frequent on still steeper slopes. For urban usage, provision of roads and other amenities will be difficult and expensive on steep slopes. Out of 11,150 hectares mapped as Ultisols only 2,140 hectares are with slopes of less

Table 7. Extent of Tropohumults in Windward Oahu[1]

Legend	Mapping Units	Area
		hectares
AeE	Alaeloa silty clay, 15 to 35 percent slopes	620
ALF	Alaeloa silty clay, 40 to 70 percent slopes	1,116
KgB	Kaneohe silty clay, 3 to 8 percent slopes	117
KgC	Kaneohe silty clay, 8 to 15 percent slopes	123
KHMC	Kaneohe silty clay loam, 5 to 15 percent slopes	140
KHME	Kaneohe silty clay loam, 15 to 30 percent slopes	85
KHMF	Kaneohe silty clay loam, 30 to 65 percent slopes	162
KHOF	Kaneohe silty clay, 30 to 65 percent slopes	162
LoB	Lolekaa silty clay, 3 to 8 percent slopes	878
LoC	Lolekaa silty clay, 8 to 15 percent slopes	187
LoD	Lolekaa silty clay, 15 to 25 percent slopes	368
LoE	Lolekaa silty clay, 25 to 40 percent slopes	703
LoF	Lolekaa silty clay, 40 to 70 percent slopes	688
PeB	Paumalu silty clay, 3 to 8 percent slopes	140
PeC	Paumalu silty clay, 8 to 15 percent slopes	194
PeD	Paumalu silty clay, 15 to 25 percent slopes	257
PeE	Paumalu silty clay, 25 to 40 percent slopes	221
PeF	Paumalu silty clay, 40 to 70 percent slopes	255

Table 7 (Continued). Extent of Tropohumults in Windward Oahu[1]

Legend	Mapping Units	Area
		hectares
WpB	Waikane silty clay, 3 to 8 percent slopes	243
WpC	Waikane silty clay, 8 to 15 percent slopes	100
WpE	Waikane silty clay, 25 to 40 percent slopes	1,610
WpF	Waikane silty clay, 40 to 70 percent slopes	2,325
WpF2	Waikane silty clay, 40 to 70 percent slopes, eroded	331
WpaE	Waikane stony silty clay, 15 to 30 percent slopes	125
		11,150

[1]Source: Foote et al. (1972)

than 15% and 1,500 hectares are with slopes of 15 to 35%. The steep slope categories and associated properties seriously affect the soil potential ratings for various uses.

Soil Classification

When soils are properly classified, they will have maximum usefulness in agriculture, engineering, planning and other disciplines. Natural relationships among soils, standardized nomenclature, and quantitative definitions are used to characterize different categories in Soil Taxonomy. Since natural relationships among the soils are used to classify different categories, behavior of closely related soils can be predicted from the experience of related soils. Soil Taxonomy incorporates soil properties that influence agricultural or nonagricultural uses at different categories and many of the criteria used in classification can be used in rating the soils.

The soil series Alaeloa, Lolekaa, Paumalu and Waikane as classified by the SCS, USDA (1972), are as follows.

Alaeloa	Orthoxic Tropohumults, clayey, oxidic, isohyperthermic
Lolekaa and Waikane	Humoxic Tropohumults, clayey, kaolinitic, isohyperthermic
Paumalu	Humoxic Tropohumults, clayey, oxidic, isohyperthermic

Based on the data obtained in this study diagnostic horizons as well as the classification of these soils are presented in Table 8. The Alaeloa soils have either ochric or mollic epipedon, while the others have either ochric or umbric epipedon. All of the soils except the Lolekaa at site L2 (Haiku) have argillic subsurface horizons. The subsurface argillic horizons are characterized by increased clay contents when compared with the surface horizons. Oriented clays, although poorly expressed, are also observed in thin sections of these soils. The poor expression of clay films in many of the argillic horizons may be due to the presence of appreciable amounts of amorphous aluminosilicates (Martini and Rajmillo, 1975). The Lolekaa soil at site L2 has no clay films or oriented clays and has a cambic horizon.

The Alaeloa soil occurs in the lower rainfall area than the Lolekaa, Paumalu and Waikane soils. The Alaeloa at site A1 (Koolau Boys' Home) has greater than 35% base saturation at all the depths examined and qualifies for an Alfisol. This soil occurs in the former caldera of the Koolau Range. Hydrothermal alteration of ferromagnesium minerals may have resulted in the high proportion of exchangeable Mg and high base status.

The Lolekaa soil at site L2 (Haiku) occurs near the Haiku post-erosional volcanic vent and is formed from pyroclastic materials. The bulk density of most of the horizons are less than 0.9 g/cm^3. This soil contains amorphous materials,

Table 8. Diagnostic Horizons and Classification of Eight Soils of Windward Oahu

Soil	Location	Surface Horizon	Subsurface Horizon	Subgroup and Family
Alaeloa	Site A1 (Koolau Boys' Home)	Ochric	Argillic	Udic Rhodustalfs clayey, kaolinitic, isohyperthermic
Alaeloa	Site A2 (Kapaa Quarry)	Mollic	Argillic	Orthoxic Tropohumults clayey, oxidic, isohyperthermic
Lolekaa	Site L1 (Kaneohe)	Umbric	Argillic	Typic Tropohumults clayey, mixed, isohyperthermic
Lolekaa	Site L2 (Haiku)	Ochric	Cambic	Andic Humitropepts clayey, mixed, isohyperthermic
Paumalu	Site P1 (Laie)	Umbric	Argillic	Typic Tropohumults clayey, kaolinitic, isohyperthermic
Paumalu	Site P2 (Puu Kauweweole)	Umbric	Argillic	Humoxic Tropohumults clayey, oxidic, isohyperthermic
Waikane	Site W1 (Kaaawa)	Ochric	Argillic	Typic Palehumults clayey, halloysitic, isohyperthermic
Waikane	Site W2 (Waiahole)	Ochric	Argillic	Typic Tropohumults clayey, mixed, isohyperthermic

hydrated halloysite, and goethite and is classified as clayey, mixed, isohyperthermic Andic Humitropepts. As this soil is not dominated by amorphous materials, particle-size modifiers are not used to describe the family.

The Alaeloa soil at site A2 (Kapaa Quarry) and the Paumalu soil at site P2 (Puu Kauweweole) have low clay activity. The Alaeloa soil at site A2 is dry at least in some part of the year and classified as Orthoxic Tropohumults. Manana series on the leeside of Koolau Range is classified similarly. The Paumalu soil at site P1 (Laie) is moist most of the years and is classified as Humoxic Tropohumults. The Leilehua and Paaloa series of the leeside of Koolau are also classified as Humoxic Tropohumults except that these soils occur in the cooler isothermic temperature regime.

The Lolekaa soil at site L1 (Kaneohe), the Paumalu soil at site P1 (Laie) and the Waikane soil at site W2 (Waiahole) have moderate clay activity and are classified as Typic Tropohumults. The Waikane soil at site W1 (Kaaawa) also has moderate clay activity but the clay distribution does not decrease by 20% from its maximum, at a depth of 1.5 m. Accordingly, this soil is classified as Typic Palehumults.

The chemical and mineralogical properties (Tables 3 and 5) and the classification of the same series differ slightly between the two pedons having similar morphology. Analysis of more pedons from each soil series will be necessary to bring out the range in characteristics and the central concept of the subgroup and family. In general, soils with moderate clay activity, that is, soils with CEC more than 24 meq/100 g (Typic Tropohumults and Typic Palehumults) occur in relatively lower rainfall areas than the soils with low clay activity (Ustoxic Tropohumults and Orthoxic Tropohumults). Under similar acidic environmental conditions, Typic Tropohumults or Typic Palehumults will have higher Al saturation. These soils require larger amounts of liming material to raise the soil pH than the Orthoxic or Ustoxic Tropohumults. Previously, Typic Tropohumults or Typic Palehumults were not reported in Hawaii.

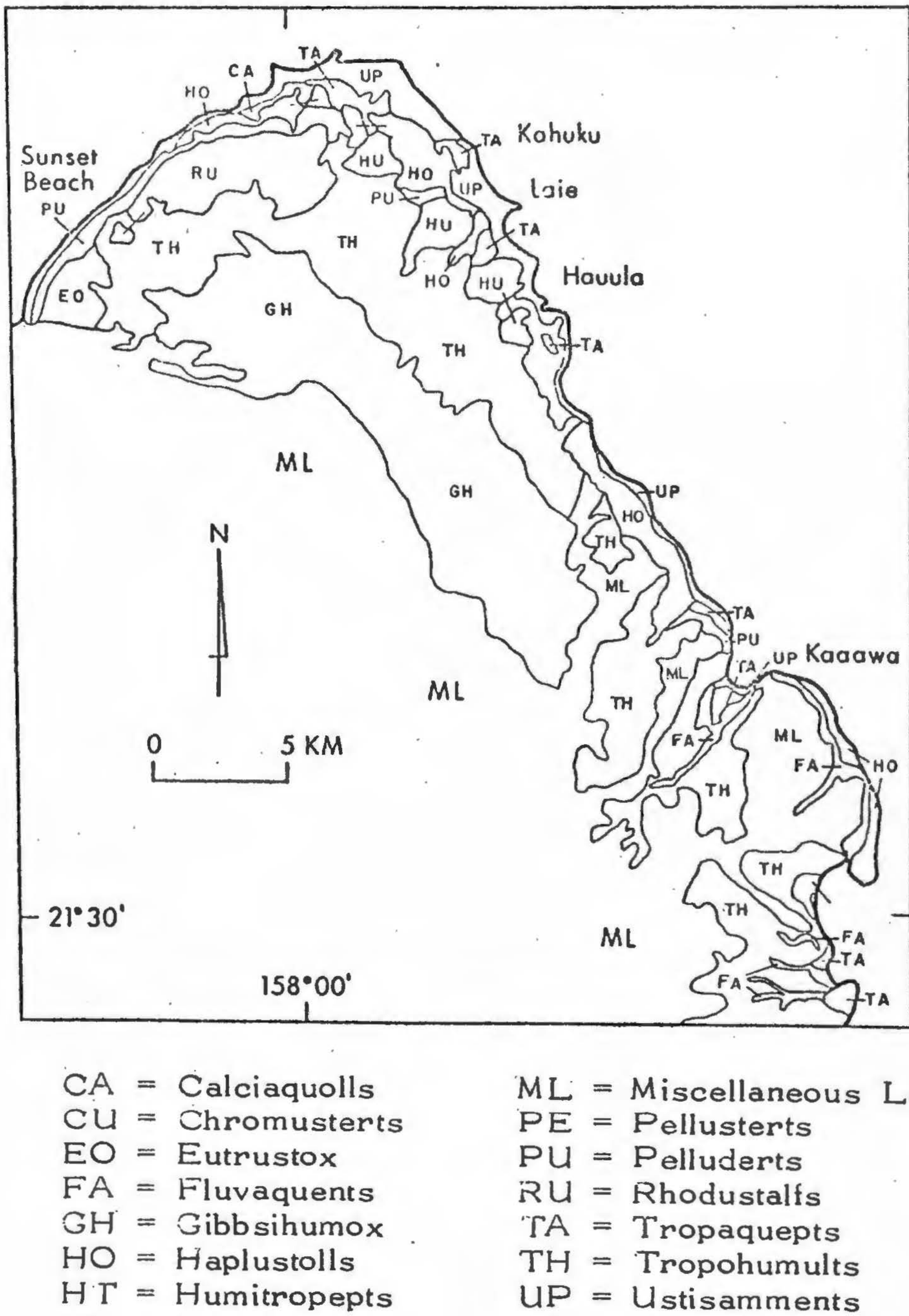
Geomorphic Relationships

The Ultisols of Hawaii generally occur on the mountain slopes of the older islands of Kauai, Maui and Oahu. In Windward Oahu, these soils occur on moderately steep to steep uplands, nearly level to gently sloping terraces, and gently sloping to very steep alluvial fans. On the south (leeward) slopes of Koolau mountain, Ultisols are bordered by Oxisols at the lower stable landscapes and rough mountainous land at higher elevations. In Windward Oahu, the prominent soil series of Ultisols, i.e., the Alaeloa, Lolekaa, Paumalu, and Waikane soils which occur from Kahuku to Waimanalo and, for the purpose of discussing the geomorphic relationships, are divided into regions from (1) Kahuku to Hauula, (2) Hauula to Heeia, and (3) Heeia to Waimanalo. The association of the Humults with the other soil groups in Windward Oahu are shown in Figures 23 and 24 and the locations of four transects are shown in Figure 25.

Kahuku to Hauula

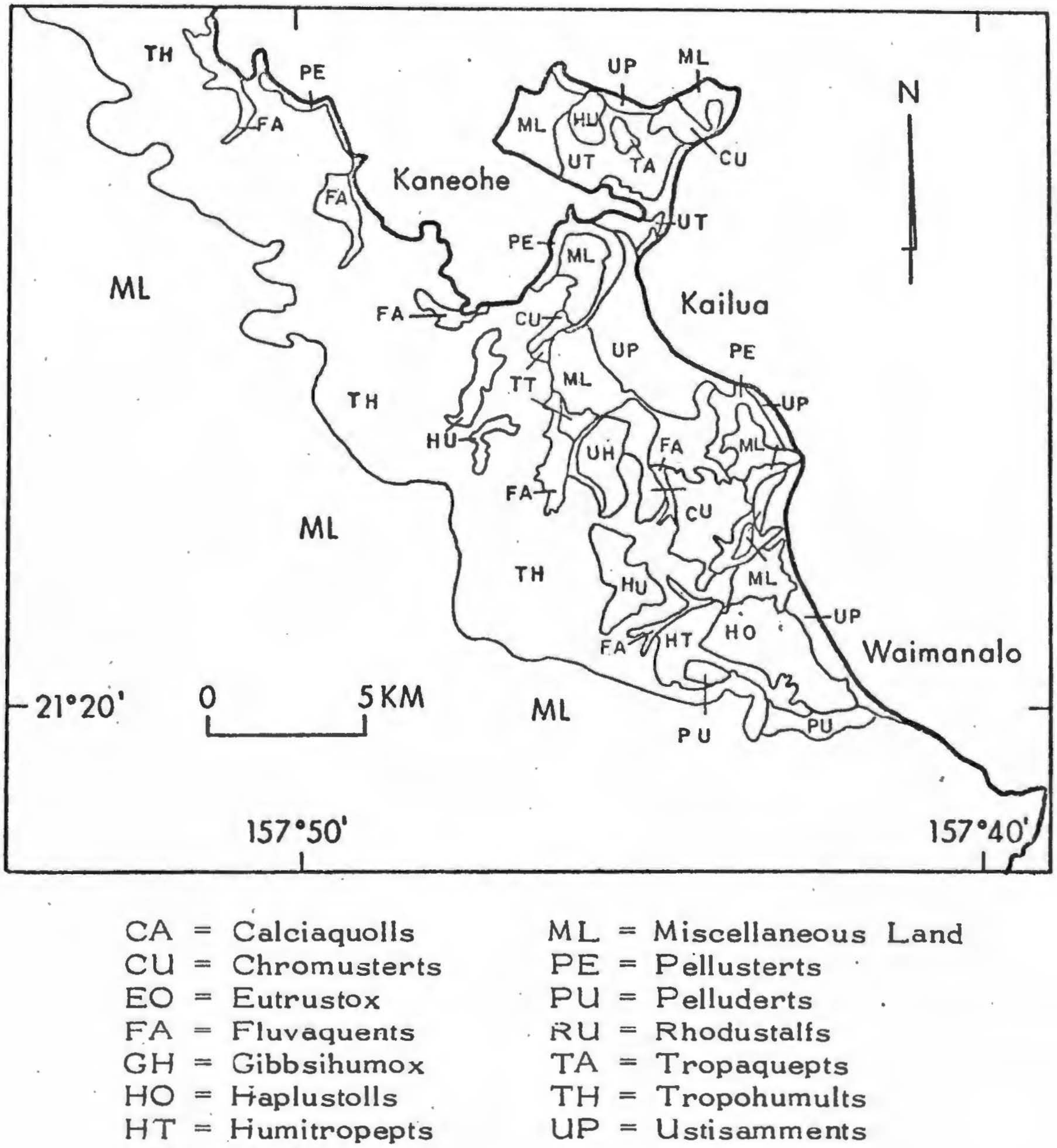
The Jaucas soils (Ustisamments), made up of coral sands and sea shells deposited by wind and water, occur along the beaches. Pearl Harbor soils (Tropaquepts) are in the poorly drained areas along the coast on alluvium overlain with organic matter. Kaena soils (Pelluderts) occur on the poorly drained fans and colluvial slopes, while the Waialua soils (Haplustolls) occur on the moderately drained lowlands.

The Paumalu series (Tropohumults) are on the uplands (230 to 330 m elevation) from Sunset Beach to Hauula. The Kemoo soils (Rhodustalfs) occur in areas that have slightly lower rainfall. The Paumalu soils are bordered by Kapaa series (Gibbsihumox) on the mountain side. The Kapaa soils are severely eroded and are on steep lands, gulches, and narrow ridges associated with numerous drainage ways. Soils along the Paumalu site P2 (Puu Kauweweole) transect are shown in Figure 26. The approximate location of the particular pedon in the transect is denoted by an (x) in the figure.



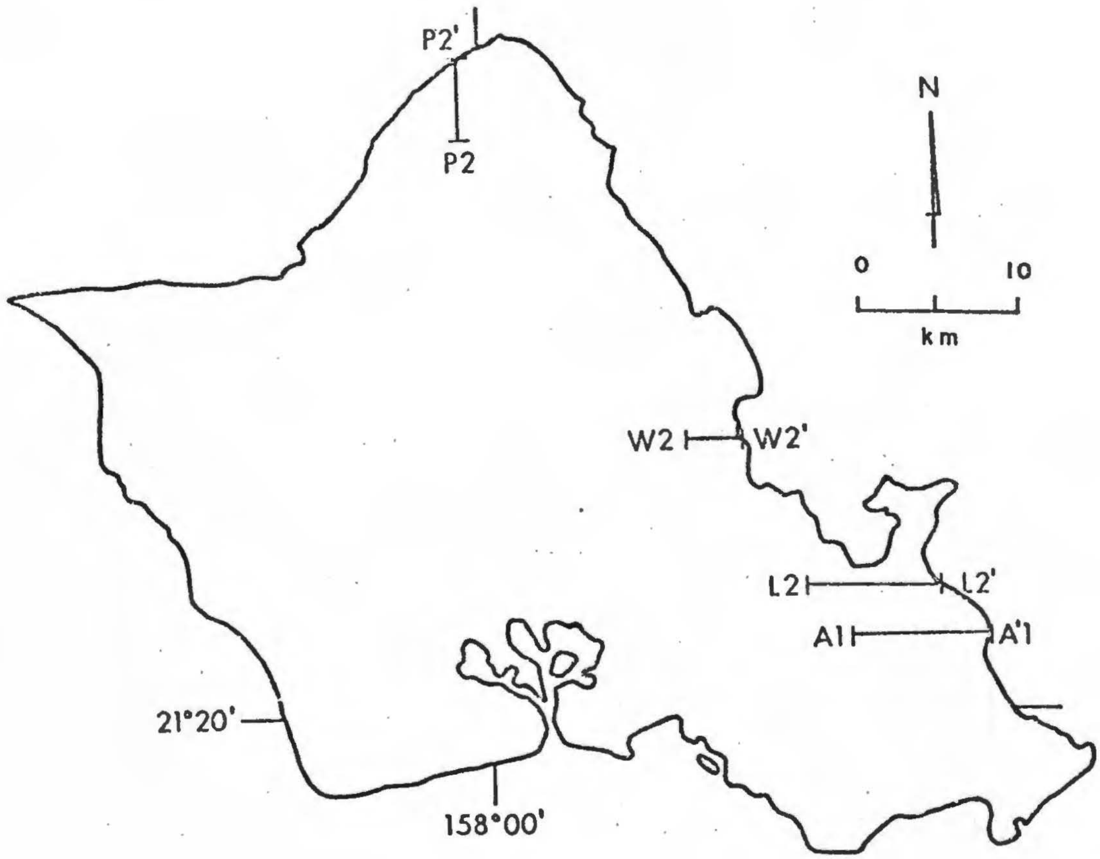
CA = Calciaquolls	ML = Miscellaneous Land
CU = Chromusterts	PE = Pellusterts
EO = Eutrustox	PU = Pelluderts
FA = Fluvaquents	RU = Rhodustalfs
GH = Gibbsihumox	TA = Tropaquepts
HO = Haplustolls	TH = Tropohumults
HT = Humitropepts	UP = Ustisamments
HU = Haplustox	

Figure 23. Distribution of the soil great groups in Windward Oahu, from Sunset Beach to Waiahole.



CA = Calciaquolls
CU = Chromusterts
EO = Eutrustox
FA = Fluvaquents
GH = Gibbsihumox
HO = Haplustolls
HT = Humitropepts
HU = Haplustox
ML = Miscellaneous Land
PE = Pellusterts
PU = Pelluderts
RU = Rhodustalfs
TA = Tropaquepts
TH = Tropohumults
UP = Ustisamments

Figure 24. Distribution of the soil great groups in Windward Oahu, from Waiahole to Waimanalo.



A1 ___ A1' = Transect through Site A1
L2 ___ L2' = Transect through Site L2
P2 ___ P2' = Transect through Site P2
W2 ___ W2' = Transect through Site W2

Figure 25. Location of transects in Windward Oahu.

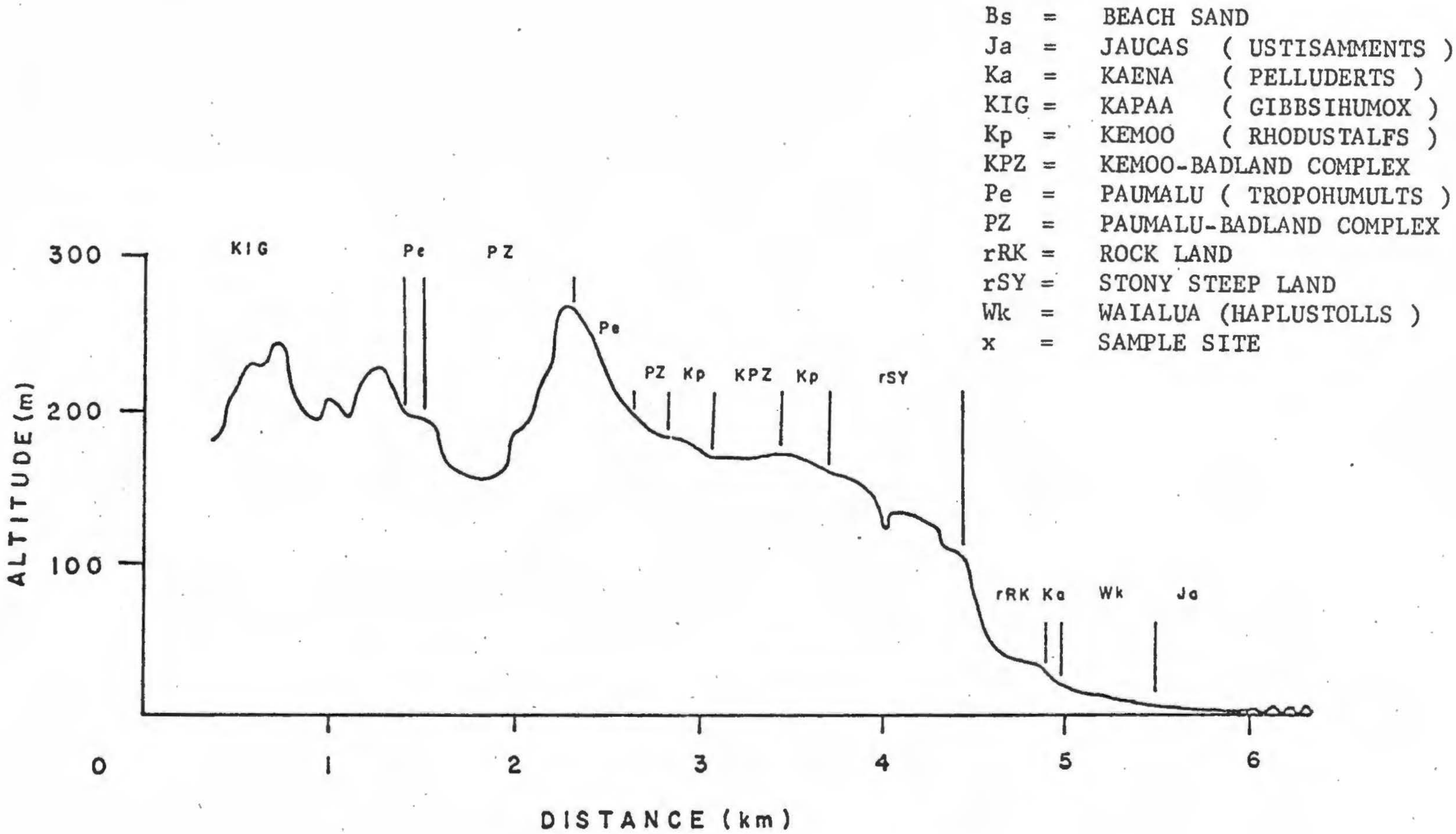


Figure 26. Longitudinal cross section of Paumalu transect.

Hauula to Heeia

The Waikane and the Lolekaa soils (Tropohumults) occur on moderately steep alluvial fans from Hauula to Heeia. The Alaeloa soils (Tropohumults) are mapped on Mount Puu Maelieli. The Hanalei soils (Fluvaquents) occur along the stream banks, while the Kawaihapai (Haplustolls) are found in the low lying areas. Soils along the Waikane site W2 (Waiahole) transect are shown in Figure 27.

Heeia to Waimanalo

The Hanalei soils occur along the major stream banks. On the other hand, the Pohukupu (Humitropepts), Waialua, and Haleiwa soils are mapped along the low lying areas of Waimanalo.

The Lolekaa is the dominant series from Lolekaa valley to Ulumawao. The Waikane or Lolekaa soils occur in the areas between Ulumawao and Puu O Kona. The Alaeloa soils occur along the lower elevations of Ulumawao and on Olomana at an elevation as high as 580 m. The Kaena soils occur on the slopes adjoining the Puu O Kona to Waimanalo. The Papaa series (Chromusterts) occur in the Keolu Hills area. The Helemano series (Haplustox) are mapped around Ulumawao and Olomana peaks. Soils along the transects Lolekaa site L2 (Haiku) and Alaeloa site A1 (Koolau Boys' Home) are shown in Figures 28 and 29.

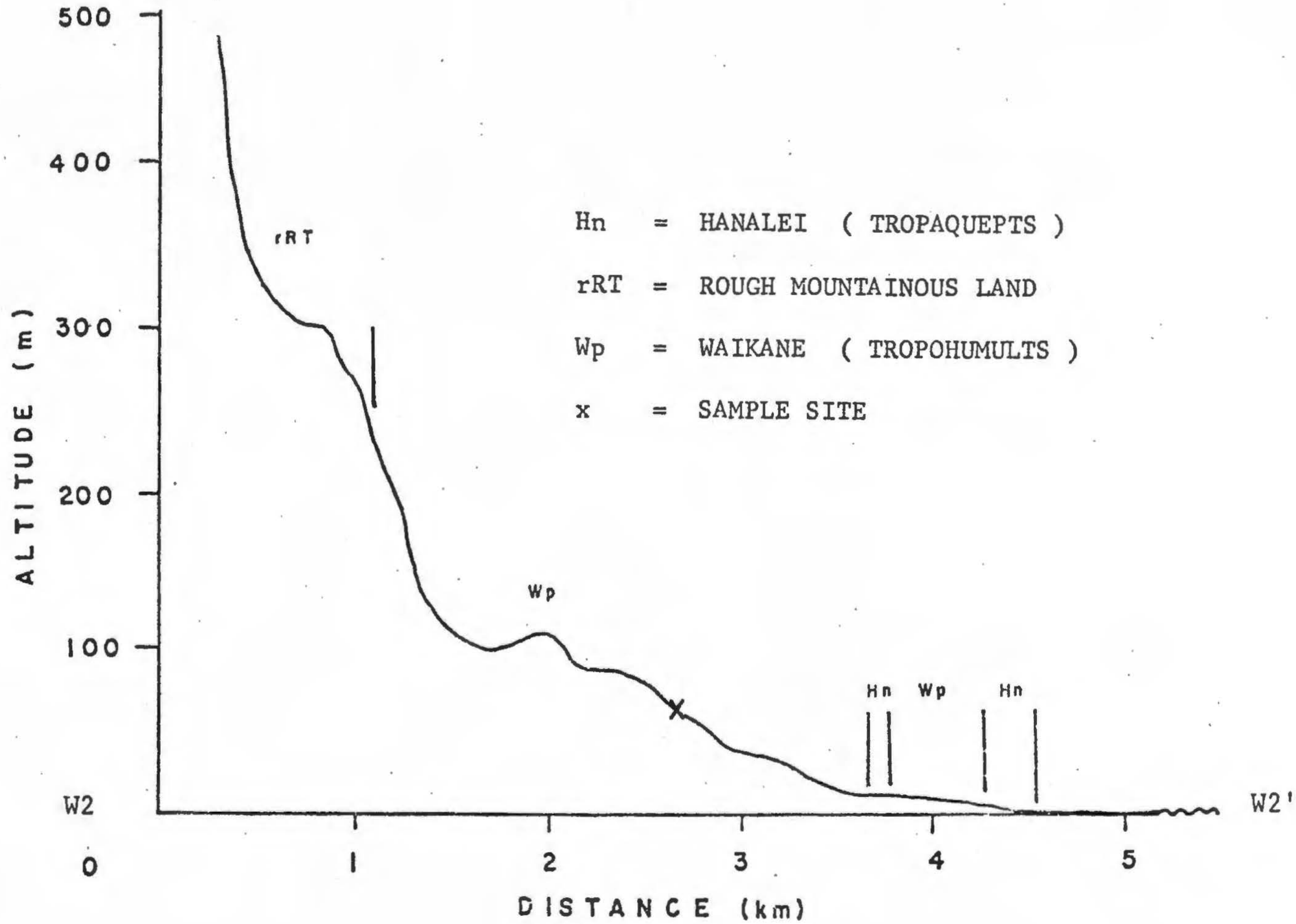


Figure 27. Longitudinal cross section of Waikane transect.

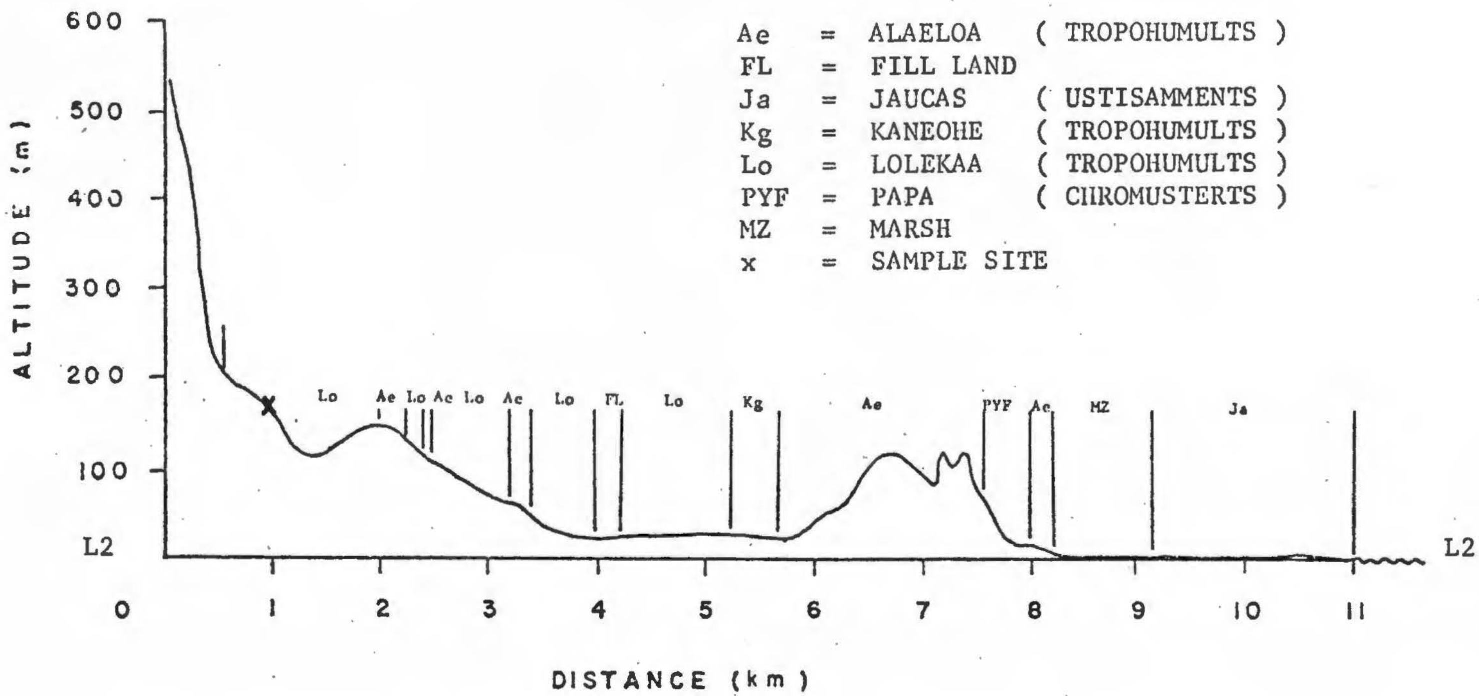


Figure 28. Longitudinal cross section of Lolekaa transect.

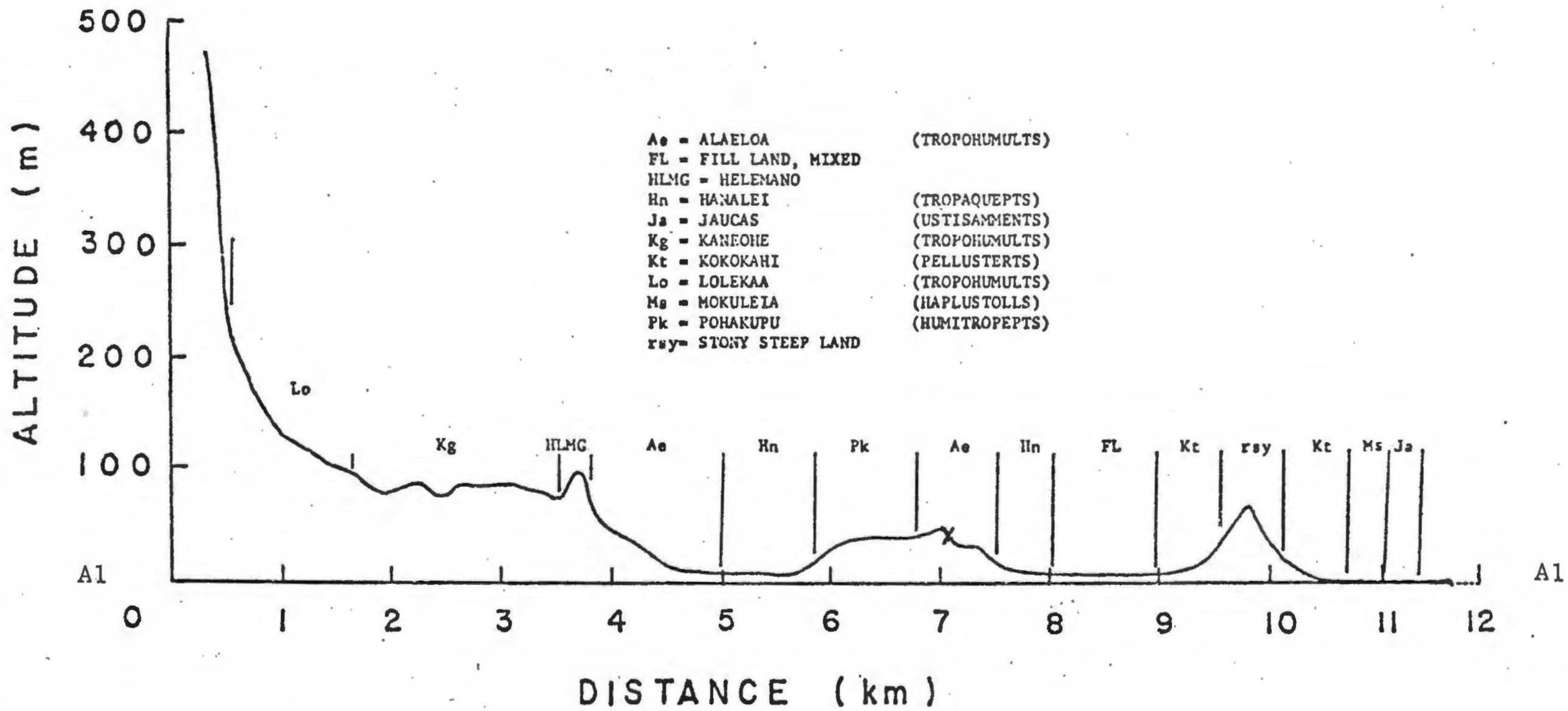


Figure 29. Longitudinal cross section of Alaeloa transect.

In general, when Oxisols and Ultisols occur side by side, Oxisols are reported to be on geomorphologically old, thick and weathered mantles, whereas Ultisols are found on geomorphologically young, shallow, and less weathered mantles (Buol et al., 1973, and Lepsch and Buol, 1974).

Soil Potential Ratings

Soil survey reports that are in print describe the limitations of soils for various uses. When a soil is described as having a severe limitation for a crop or for some specific nonagricultural use, the farmer or the landowner who already owns the land is faced with problems (Davis, 1975).

To a certain extent, a particular soil with severe limitation can be made productive with proper inputs of management. These inputs may be easily feasible or may require much technology and cost.

One of the aims of the Soil Conservation Service, USDA, therefore, is to take a positive approach, the "soil potentials" approach (Davis, 1975). This approach is to provide the land user with more information about soil behavior so that he can better utilize the soil. When the "soil potentials" approach is fully developed, the published soil surveys, which will incorporate this approach, is expected to become more useful.

As mentioned in the introduction, one of the objectives of this investigation is to propose a method of rating the potentials of soils for specific agricultural and nonagricultural uses.

Some of the Existing Approaches to Land Classification

The term "soil" implies a limited body. Thus, it is necessary to use the term "land" to cover a larger area which includes not only soil, but also water, biosphere, and other natural resources. In evaluating an area for general or specific use, therefore, it is necessary to judge the suitability of the land. Accordingly, some of the existing approaches of land classification are reviewed in the following sections.

Land-Capability Classification. One of the approaches to land classification is the Land-Capability Classification presented by Klingebiel and Montgomery (1961). The classification is an interpretive groupings of soils primarily for agriculture. There are eight capability classes. Classes I through IV are lands suited to cultivation and other uses; Class I with least limitations and Class IV with severe limitations. In addition, Classes V through VIII are lands with limited use, generally not suited for cultivation. Again, Class V has least limitations and Class VIII has the most severe limitations.

The classes are subdivided into lower categories, the subclass and the capability unit, to accommodate the kinds of limitations or hazards (e.g., erosion hazard, wetness, rooting-zone limitations, and climate) and to group soils that respond similarly to systems of management of common cultivated crops and pasture plants. The use of the class and subclass gives the limitation and problem of the soil. For example, a soil classified as Class III(e) means that this soil has "severe limitations that reduce the choice of plants or require special conservation practices or both" and it is Class III because of the risks of erosion (e).

There are many kinds of soils. One of the advantages of the Land-Capability Classification is that similar soils with similar capabilities and limitations are grouped together. Land use planning or interpretations for cultivated crops can thus be made for an aggregate of soil mapping units which may exist within a farm or within a larger regional area.

On the other hand, grouping of the similar soils may preclude the evaluation of a given soil mapping unit. If maximum or intensive use of a soil mapping unit is intended, such a practice is not easily possible. Other disadvantages of the Land-Capability Classification appear to be that this system is primarily for agricultural interpretation and that limitations rather than potentials are emphasized.

Storie Index. The Storie Index, introduced by Storie (1933) and modified several times, is used to evaluate land based on factors such as the character of the profile, texture, and soil modifying conditions; for example, slope. A multiplicative, rather than an additive, approach is used to show the dominating influence of a limiting factor. This approach is approved by many (e.g., Sahara et al., 1972; Riquier, 1972) over the additive approach which does not seem to emphasize the limiting factor of a particular soil. The disadvantage of the Storie Index is the repetitive use of characteristics inherent in the soil series in calculating the index. Furthermore, this index is developed for California soils and requires modification to the procedure if used elsewhere.

Detailed Land Classification Based on Productivity Ratings. In Hawaii, the former Land Study Bureau of the University of Hawaii prepared a detailed land classification based on productivity ratings (Sahara et al., 1972). This particular publication is for the island of Oahu, but earlier publications by the Bureau are devoted to the other islands, so that in effect, there is a detailed land classification for the entire State.

Briefly, the land classification is an evaluation of the productive capacity of the land for (1) selected crops and uses (pineapple, vegetables, sugarcane, forage, grazing, orchard, and forestry) and (2) overall suitability in agricultural use. The former is called the Selected Crop Productivity Rating while the latter is called the Overall Productivity Rating.

The evaluation was made on land type, "a group of agricultural lands with similar physical productivities when subjected to a given set of cultural practices, owing to similar chemical and physical soil properties, topography, climate and modifying features" (Sahara et al., 1972).

If land types are considered, this method of evaluation can be most useful. The published soil surveys of Hawaii, however, give the soil mapping units as the basic units, and because the boundaries of the land types and the soil mapping units are not necessarily the same, there is some difficulty in comparing the two methods. Perhaps, the Modified Storie Index, which is used to evaluate the land types, could be used to evaluate the soil mapping units, or conversely, the "soil potentials" approach could be used to evaluate the land types. Comparison of the results should be interesting and the results may suggest that either of the approaches may be suitable for land evaluation in Hawaii.

Other Systems of Land Classification. Other systems of land classification are reviewed by Olson (1974), Boyer (1974), and Teaci and Burt (1974). These reviews are most useful because they provide different ideas on land classification.

Concept of Soil Potentials

As indicated earlier, the purpose of the "soil potentials" approach is to provide a land user with more information about a soil so that he can better utilize that soil. Because soil and landscape parameters differ just as crops differ, the "soil potentials" approach by necessity requires a specific calculation for each use, agricultural or nonagricultural. Furthermore, the calculation of the soil potential for a specific use requires a thorough understanding of the fundamentals of soil and crop sciences.

It should be emphasized that the calculation of soil potentials is not easy. In fact, caution is expressed to the inexperienced soil interpreter that substituting prescribed criteria with given ratings and weightings in a similar fashion for every use could lead to misleading interpretation. The assignment of the weightings, the judgment factor, to the ratings for a given criterion of a parameter requires more than casual knowledge. It is true that this assignment of the weightings may appear subjective, but when the judgment is made based on experience, the weighting and the rating can become meaningful in soil interpretation.

The ideal model for calculating soil potentials for crops should be based on crop yield data, while that for calculating the potentials for nonagricultural uses should be based on specific behavior. Crop yield is a function of soil, climate, plant, and management factors. By experimentation, the parameters that influence yield can be determined and statistical treatment, such as a regression equation, can be developed to predict the yields of crops on soils that have similar properties (Silva and

Beinroth, 1975). Development of such a yield prediction, however, accommodating variations in soil properties as well as climate, plant, and management factors, can be highly expensive and time-consuming.

When exact ratings cannot be obtained, the general behavior and the data of soils that are similarly classified can be used as guides in rating the soils in question.

A Proposed Approach to the Determination of Soil Potentials

Several approaches or models can be used to illustrate the concept of soil potentials. The additive, subtractive, multiplicative, and complex equations, for example, are discussed by Riquier (1972). Despite the limitations of the additive (linear additive) model, this approach will be used in this investigation because of its simplicity. Later, efforts can be made not only to improve the choice of parameters and criteria, but also to select reasonable ratings, as well as their weightings, of the criteria.

Brief Description of the Additive Model. Once the parameters, features, or characteristics are selected for a rating, the sum of the component parameters can be obtained according to the procedure suggested by Bartelli and Ikawa (1973):

$$SPI = \sum_{i=1}^{n} W_i I_i + \sum_{j=1}^{n} W_j J_j$$

where SPI = Soil potential index

W_i = Weightings associated with parameter I

I_i = Rating or value of parameter I

(e.g., a noncontrollable parameter)

W_j = Weightings associated with parameter J

J_j = Rating or value of parameter J

(e.g., a controllable parameter)

The parameters to be used would depend on the potential rating being determined for a given use and would be obtained from guides such as the "Guide for Interpreting Engineering Uses of Soils" (SCS, 1971) or from selected lists prepared for specific uses (e.g., Bartelli et al., 1976).

These parameters, furthermore, could be considered as being either noncontrollable or controllable (Uehara and Ikawa, 1974). The former would be parameters that normally could not be altered by man (e.g., slope, texture, or mineralogy), while the latter would be parameters that could be altered or managed by man (e.g., soil pH).

Assembly of Data. Unpublished and published data; for example, the data obtained in this study as well as those in the published soil survey (Foote et al., 1972) and in Soil Survey Investigations Report 29 (SCS et al., 1976), could be compiled to calculate the soil potentials for selected uses.

For this study, only those data that were used to calculate the potentials for the production of banana and sweet potato and for dwellings and construction of local roads or streets are presented in Tables 9 and 10. The controllable parameters (Table 10), unless otherwise indicated, were recalculated for the 0 to 50-cm depth by using the data presented in Table 3. The parameters used for the selected uses are listed in Table 11. This table also shows that parameters which are not limiting factors are not used. For example, for the study site, parameters such as depth of soil, drainage, and previousness (permeability) are generally the same or are near optimum for the production of banana and sweet potato.

Calculation of Soil Potentials. Using the procedure proposed by Bartelli et al. (1976) as a guide, the lists of criteria, weightings, ratings, and possible scores of the different parameters were prepared as Tables 12, 14, 16, and 18. These tables were then in turn used to calculate the soil potentials for selected uses as shown in Tables 13, 15, 17, and 19.

The method of calculation to obtain the soil potentials for selected uses is illustrated by an example for soil mapping unit LoB in Appendix B.

Based on score percentage, the soil mapping units for each use have been rated as being either good, fair, or poor. The three-class system of rating soil potentials is essentially that proposed by the Soil Conservation Service. In this study, the

Table 9. Summary of the Noncontrollable and Landscape-Parameter Data of the Humults of Windward Oahu

Mapping Unit	Slope	Texture	Mineralogy	Unified Soil Group[1]	Shrink-Swell Potential[2]	Depth to Bedrock[1]	Depth to Water Table[1]	Flooding[3]	Stoniness[3]	Rockiness[3]
	%					m	m		class	class
AoE	15-35	clay loam	oxidic	MH	Low	>1.5	>1.5	None	0	0
ALF	40-70	clay loam	oxidic	MH	Low	>1.5	>1.5	None	0	0
LoB	3- 8	clay	mixed	MH	Moderate	>1.5	>1.5	None	0	0
LoC	8-15	clay	mixed	MH	Moderate	>1.5	>1.5	None	0	0
LoD	15-25	clay	mixed	MH	Moderate	>1.5	>1.5	None	0	0
LoE	25-40	clay	mixed	MH	Moderate	>1.5	>1.5	None	0	0
LoF	40-70	clay	mixed	MH	Moderate	>1.5	>1.5	None	0	0
PeB	3- 8	clay	oxidic	MH	Low	>1.5	>1.5	None	0	0
PeC	8-15	clay	oxidic	MH	Low	>1.5	>1.5	None	0	0
PeD	15-25	clay	oxidic	MH	Low	>1.5	>1.5	None	0	0
PeE	25-40	clay	oxidic	MH	Low	>1.5	>1.5	None	0	0
PeF	40-70	clay	oxidic	MH	Low	>1.5	>1.5	None	0	0
WpB	3- 8	clay	halloysitic	MH	Moderate	>1.5	>1.5	None	0	0
WpC	8-15	clay	halloysitic	MH	Moderate	>1.5	>1.5	None	0	0
WpE	25-40	clay	halloysitic	MH	Moderate	>1.5	>1.5	None	0	0
WpF	40-70	clay	halloysitic	MH	Moderate	>1.5	>1.5	None	0	0
WpF 2	40-70	clay	halloysitic	MH	Moderate	<1.5[3]	>1.5	None	0	1
WpaE	15-30	stony silty clay[3]	halloysitic	MH	Moderate	>1.5	>1.5	None	1	0

[1]Data from Foote et al. (1972).

[2]Estimated data from experimental data (texture and mineralogy).

[3]Estimated data from soil series descriptions (Foote et al., 1972).

Table 10. Summary of the Controllable Soil and Landscape-Parameter Data of the Humults of Windward Oahu

Mapping Unit	Moisture Regime	pH	P Fixation[2]	Al Saturation	Base Saturation	Organic C	K Content
			μg/g	%	%	%	meq/100 g
		A[3] B[3]	A B	A B	A B	A B	A B
AeE	ustic	--, 5.3	--, 220	--, 19	--, 29	--, 1.55	--, 0.34
ALF	"	--, 5.3	--, 220	--, 19	--, 29	--, 1.55	--, 0.34
LoB	udic	5.1, 4.8	580, --	49, 28	24, 25	2.09, 2.58	0.33, 0.36
LoC	"	5.1, 4.8	580, --	49, 28	24, 25	2.09, 2.58	0.33, 0.36
LoD	"	5.1, 4.8	580, --	49, 28	24, 25	2.09, 2.58	0.33, 0.36
LoE	"	5.1, 4.8	580, --	49, 28	24, 25	2.09, 2.58	0.33, 0.36
LoF	"	5.1, 4.8	580, --	49, 28	24, 25	2.09, 2.58	0.33, 0.36
PeB	"	4.7, 4.9	--, 220	25, 3	39, 36	2.96, 2.97	0.34, 0.55
PeC	"	4.7, 4.9	--, 220	25, 3	39, 36	2.96, 2.97	0.34, 0.55
PeD	"	4.7, 4.9	--, 220	25, 3	39, 36	2.96, 2.97	0.34. 0.55
PeE	"	4.7, 4.9	--, 220	25, 3	39, 36	2.96, 2.97	0.34, 0.55
PeF	"	4.7, 4.9	--, 220	25, 3	39, 36	2.96, 2.97	0.34, 0.55
WpB	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31
WpC	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31
WpE	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31
WpF	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31
WpF2	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31
WpaE	"	5.0, 4.9	735, --	61, 33	15, 19	2.45, 2.83	0.21, 0.31

[1]Data from one or two pedons (0 to 50-cm soil depth); Alaeloa data from site A2; first Lolekaa data from site L1; second Lolekaa data from SCS et al. (1976).

[2]P fixation with 0.05 ppm P in soil solution (0 to 35-40-cm soil depth).

[3]A = pedon 1; B = pedon 2.

Table 11. List of Parameters Used to Calculate the Potentials for Selected Uses in the Humults of Windward Oahu

Parameters	Uses			
	Banana	Sweet Potato	Dwellings	Roads/Streets
<u>Noncontrollable</u>:				
Slope	x	x	x	x
Texture	x	x		
Mineralogy	x	x		
Unified soil group			x	x
Shrink-swell potential			x	x
Depth to bedrock				x
Seasonal water table			x	
Flooding			x	x
Stoniness				x
Rockiness				x
Drainage			x	x
<u>Controllable</u>:				
Moisture regime	x	x		
pH	x	x		
P fixation	x	x		
Al saturation	x	x		
Base saturation	x	x		
Organic C	x	x		
K content	x	x		

Table 12. Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Production of Banana in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Slope	6	0- 8%	5	30
		8-15	4	24
		15-25	3	18
		25-50	2	12
		>50	1	6
Texture	5	loamy	3	15
		clayey	2	10
		sandy, stony	1	5
Mineralogy	4	2:1 minerals, mixed	3	12
		1:1 minerals, mixed	2	8
		oxides, mixed	1	4
Moisture regime	4	udic	3	12
		ustic	2	8
		aridic	1	4
pH	2	5-7	3	6
		4.5-5, 7-8	2	4
		<4.5, >8	1	2
P fixation	2	<250 μg/g	3	6
		250-500	2	4
		>500	1	2
Al saturation	2	<35%	3	6
		35-60	2	4
		>60	1	2
Base saturation	1	>35%	3	3
		15-35	2	2
		<15	1	1

Table 12 (Continued). Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Production of Banana in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Organic C	1	>3%	3	3
		1.5-3	2	2
		<1.5	1	1
K content	1	>1 meq/100 g	3	3
		0.1-1	2	2
		<0.1	1	1

[1]Low number = least influence; high number = most influence.

[2]Low number = least favorable; high number = most favorable.

Table 13. Ratings and Score Matrix of the Soil Mapping Units to Determine the Potential for the Production of Banana in the Humults of Windward Oahu

Mapping Unit[1]	Noncontrollable Parameters						Controllable Parameters							Overall Score and Rating		
	Slope	Texture	Mineralogy	Sum of Scores	Score %	Ratings[2]	Moisture Regime	pH	P Fixation	Al Saturation	Base Saturation	Organic C	K Content	Sum of Scores	Score %	Ratings[3]
AeE	18	15	4	37	64	Fair	8	6	6	6	2	2	2	69	71	Fair
ALF	6	15	4	25	43	Poor	-	-	-	-	-	-	-	-	-	Poor
LoB	30	10	8	48	84	Good	12	4	2	4	2	2	2	76	79	Good
LoC	24	10	8	42	73	Good	12	4	2	4	2	2	2	70	72	Fair
LoD	18	10	8	36	63	Fair	12	4	2	4	2	2	2	64	66	Fair
LoE	12	10	8	30	52	Fair	12	4	2	4	2	2	2	58	60	Poor
LoF	6	10	8	24	42	Poor	-	-	-	-	-	-	-	-	-	Poor
PeB	30	10	4	44	77	Good	12	4	6	6	3	2	2	79	82	Good
PeC	24	10	4	38	66	Fair	12	4	6	6	3	2	2	73	76	Good
PeD	18	10	4	32	56	Fair	12	4	6	6	3	2	2	67	69	Fair
PeE	12	10	4	26	45	Poor	-	-	-	-	-	-	-	-	-	Poor
PeF	6	10	4	20	35	Poor	-	-	-	-	-	-	-	-	-	Poor
WpB	30	10	8	48	84	Good	12	4	2	4	2	2	2	76	79	Good
WpC	24	10	8	42	73	Good	12	4	2	4	2	2	2	70	72	Fair
WpE	12	10	8	30	52	Fair	12	4	2	4	2	2	2	58	60	Poor
WpF	6	10	8	24	42	Poor	-	-	-	-	-	-	-	-	-	Poor
WpF2	6	10	8	24	42	Poor	-	-	-	-	-	-	-	-	-	Poor
WpaE	18	5	8	31	54	Fair	12	4	2	4	2	2	2	59	61	Poor
Maximum Scores Possible	30	15	12	57	100		12	6	6	6	3	3	3	96	100	

[1]For description of mapping units, see Table 20.

[2]Good = 70-100%; Fair = 50-69%; Poor = <50%.

[3]Good = 75-100%; Fair = 65-74%; Poor = <65%.

Table 14. Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Production of Sweet Potato in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Slope	6	0- 8%	5	30
		8-15	4	24
		15-25	3	18
		25-50	2	12
		>50	1	2
Texture	5	loamy	4	20
		clayey (1:1 oxides)	2	10
		clayey (2:1)	1	5
Mineralogy	4	2:1 minerals, mixed	3	12
		1:1 minerals, mixed	2	8
		oxides, mixed	1	4
Moisture regime	4	udic	3	12
		ustic	2	8
		aridic	1	4
pH	3	5.5-6.5	3	9
		4.5-5.5	2	6
		<4.5	1	3
P fixation	1	<250 μg/g	3	3
		250-1000	2	2
		>1000	1	1
Al saturation	1	<35%	3	3
		35-60	2	2
		>60	1	1
Base saturation	1	>35%	3	3
		15-35	2	2
		<15	1	1

Table 14 (Continued). Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Production of Sweet Potato in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Organic C	1	>3%	3	3
		1.5-3	2	2
		<1.5	1	1
K content	1	>1 meq/100 g	3	3
		0.1-1	2	2
		<0.1	1	1

[1]Low number = least influence; high number = most influence.

[2]Low number = least favorable; high number = most favorable.

Table 15. Ratings and Score Matrix of the Soil Mapping Units to Determine the Potential for the Production of Sweet Potato in the Humults of Windward Oahu

Mapping Unit[1]	Noncontrollable Parameters						Controllable Parameters							Overall Score and Rating		
	Slope	Texture	Mineralogy	Sum of Scores	Score %	Ratings[2]	Moisture Regime	pH	P Fixation	Al Saturation	Base Saturation	Organic C	K Content	Sum of Scores	Score %	Ratings[3]
AeE	18	20	4	42	67	Fair	8	6	3	3	2	2	2	68	69	Fair
ALF	6	20	4	30	48	Poor	-	-	-	-	-	-	-	-	-	Poor
LoB	30	10	8	48	77	Good	12	6	2	2	2	2	2	76	77	Good
LoC	24	10	8	42	67	Fair	12	6	2	2	2	2	2	70	71	Fair
LoD	18	10	8	36	58	Fair	12	6	2	2	2	2	2	64	65	Fair
LoE	12	10	8	30	48	Poor	-	-	-	-	-	-	-	-	-	Poor
LoF	6	10	8	24	38	Poor	-	-	-	-	-	-	-	-	-	Poor
PeB	30	10	4	44	70	Good	12	6	3	3	3	2	2	75	76	Good
PeC	24	10	4	38	61	Fair	12	6	3	3	3	2	2	69	70	Fair
PeD	18	10	4	32	51	Fair	12	6	3	3	3	2	2	63	64	Poor
PeE	12	10	4	26	41	Poor	-	-	-	-	-	-	-	-	-	Poor
PeF	6	10	4	20	32	Poor	-	-	-	-	-	-	-	-	-	Poor
WpB	30	10	8	48	77	Good	12	6	2	2	2	2	2	76	77	Good
WpC	24	10	8	42	67	Fair	12	6	2	2	2	2	2	70	71	Fair
WpE	12	10	8	30	48	Poor	-	-	-	-	-	-	-	-	-	Poor
WpF	6	10	8	24	38	Poor	-	-	-	-	-	-	-	-	-	Poor
WpF2	6	10	8	24	38	Poor	-	-	-	-	-	-	-	-	-	Poor
WpaE	18	5	8	31	50	Fair	12	6	2	2	2	2	2	59	60	Poor
Maximum Scores Possible	30	20	12	62	100		12	9	3	3	3	3	3	98	100	

[1]For description of mapping units, see Table 20.

[2]Good = 70-100%; Fair = 50-69%; Poor = <50%.

[3]Good = 75-100%; Fair = 65-74%; Poor = <65%.

Table 16. Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for Dwelling Sites in the Humults of Windward Oahu

Parameters[1]	Weightings[2] (W)	Criteria	Ratings[3] (R)	Possible Scores (W x R)
Slope	3	0- 8%	5	15
		8-15	4	12
		15-30	3	9
		30-45	2	6
		>45	1	3
Shrink-swell potential	2	low	3	6
		moderate	2	4
		high	1	2
Unified soil group	2	MH	3	6
		ML	1	3
Water table	1	>75 cm	3	3
		50-75	2	2
		<25	1	1
Flooding	1	none	3	3
		rare, occasional, frequent	1	1
Drainage class	1	well drained	3	3
		somewhat poorly drained	2	2
		poorly drained	1	1

[1]For additional information, see Guide for Interpreting Engineering Uses of Soils (1971), p. 31.

[2]Low number = least influence; high number = most influence.

[3]Low number = least favorable; high number = most favorable.

Table 17. Ratings and Score Matrix of the Soil Mapping Units to Determine the Potential for Dwelling Sites in the Humults of Windward Oahu

Mapping Unit	Slope	Shrink-Swell Potential	Unified Soil Group	Flooding	Drainage	Water Table	Sum of Scores	Score %	Ratings
AeE[1]	9	6	6	3	3	3	30	83	Fair
ALF	3	6	6	3	3	3	24	66	Poor
LoB	15	4	6	3	3	3	34	94	Good
LoC	12	4	6	3	3	3	31	86	Good
LoD	9	4	6	3	3	3	28	77	Fair
LoE	6	4	6	3	3	3	25	69	Poor
LoF	3	4	6	3	3	3	22	61	Poor
PeB	15	6	6	3	3	3	36	100	Good
PeC	12	6	6	3	3	3	33	91	Good
PeD	9	6	6	3	3	3	30	83	Fair
PeE	6	6	6	3	3	3	27	75	Fair
PeF	3	6	6	3	3	3	24	66	Poor
WpB	15	4	6	3	3	3	34	94	Good
WpC	12	4	6	3	3	3	31	86	Good
WpE	6	4	6	3	3	3	25	69	Poor
WpF	3	4	6	3	3	3	22	61	Poor
WpF2	3	4	6	3	3	3	22	61	Poor
WpaE	9	4	4	3	3	3	26	72	Poor
Maximum Possible Scores	15	6	6	3	3	3	36	100	

[1]For description of mapping units, see Table 20.
Good = 85-100%; Fair = 75-84%; Poor = Less than 75%.

Table 18. Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Construction of Local Roads or Streets in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Slope	3	0- 8%	5	15
		8-15	4	12
		15-30	3	9
		30-45	2	6
		>45	1	3
Shrink-swell potential	2	low	3	6
		moderate	2	4
		high	1	2
Flooding	1	none	3	3
		less than once in 5 years	2	2
		more than once in 5 years	1	1
Drainage class	1	well drained	3	3
		somewhat poorly drained	2	2
		poorly drained	1	1
Depth to bedrock	1	>100 cm	3	3
		50-100	2	2
		<50	1	1

Table 18 (Continued). Criteria, Weightings, Ratings, and Possible Scores of Parameters to Calculate the Potential for the Construction of Local Roads or Streets in the Humults of Windward Oahu

Parameters	Weightings[1] (W)	Criteria	Ratings[2] (R)	Possible Scores (W x R)
Stoniness class[3]	1	0, 1, 2	3	3
		3	2	2
		4, 5	1	1
Rockiness class[3]	1	0	3	3
		1	2	2
		2, 3, 4, 5	1	1
Unified soil group	1	MH	3	3
		ML	1	1

[1]Low number = least influence; high number = most influence.

[2]Low number = least favorable; high number = most favorable.

[3]For class information, see Soil Survey Manual.

Table 19. Ratings and Score Matrix of the Soil Mapping Units to Determine the Potential for the Construction of Local Roads or Streets

Mapping Unit	Slope	Shrink-Swell Potential	Flooding	Drainage	Depth to Bedrock	Stoniness	Rockiness	Unified Soil Group	Sum of Scores	Score %	Ratings
AoE[1]	9	6	3	3	3	3	3	3	33	84	Fair
ALF	3	6	3	3	3	3	3	3	27	69	Poor
LoB	15	4	3	3	3	3	3	3	37	94	Good
LoC	12	4	3	3	3	3	3	3	34	87	Fair
LoD	9	4	3	3	3	3	3	3	31	79	Poor
LoE	6	4	3	3	3	3	3	3	28	71	Poor
LoF	3	4	3	3	3	3	3	3	25	64	Poor
PeB	15	6	3	3	3	3	3	3	39	100	Good
PeC	12	6	3	3	3	3	3	3	36	92	Good
PeD	9	6	3	3	3	3	3	3	33	84	Fair
PeE	6	6	3	3	3	3	3	3	30	76	Poor
PeF	3	6	3	3	3	3	3	3	27	69	Poor
WpB	15	4	3	3	3	3	3	3	37	94	Good
WpC	12	4	3	3	3	3	3	3	34	87	Fair
WpE	6	4	3	3	3	3	3	3	28	71	Poor
WpF	3	4	3	3	3	3	3	3	25	64	Poor
WpF2	3	4	3	3	2	3	3	3	24	61	Poor
WpaE	9	4	3	3	3	3	3	3	31	79	Poor
Maximum Scores Possible	15	6	3	3	3	3	3	3	39	100	

[1]For description of mapping units, see Table 20.
Good = 90-100%; Fair = 80-89%; Poor = Less than 80%.

soils are rated poor when the parameters are expected to limit crop production seriously or to cause environmental deterioration significantly. The soils are rated fair or good when these parameters are moderately favorable or favorable for crop production or have minimum effect on the environment. In general, then, soils that are expected to produce or behave above average, average, and below average yield or performance are rated as being good, fair, or poor, respectively. It must be emphasized that the three-class system is intended to reflect the present fertility or behavior of the soils for a specific use. With management, soils that are rated as being fair or poor can have a higher potential, provided that the noncontrollable parameters are not the dominant limiting factor.

Soil Potentials for Agricultural and Nonagricultural Uses

Tables 13 and 15 show the soil potentials for the production of banana and sweet potato, respectively. In general, soils which are rated as being good, based on noncontrollable parameters, are also rated good based on overall rating. Similar relationships exist for soils being rated fair and poor. There are instances, however, when a soil rated as being good based on noncontrollable parameters is rated overall fair because of the influence of the controllable parameters. Similarly, a soil rated fair based on noncontrollable parameters is rated overall good or poor.

These data, therefore, show that noncontrollable parameters have strong influence on the rating of soils for production of banana and sweet potato. Furthermore, the major limiting factor for the production of banana and sweet potato in the Humults of Windward Oahu is the steep slope. Such a conclusion was to be expected because the tables of parameters, criteria, and rating (Tables 12 and 14) placed greater emphasis on the noncontrollable parameters. Further study of Tables 13 and 15 shows that soils which are suited for banana are equally suited for sweet potato.

Tables 17 and 19 show the soil potentials for dwelling sites and for construction of local roads or streets, respectively. As shown in these tables and in Table 11, all of the parameters are noncontrollable parameters. In other words, soil potentials for nonagricultural uses, as illustrated by this study, are dominated by the noncontrollable parameters. Such an observation would suggest that soils that are most suited for the production of banana and sweet potato (assuming that noncontrollable parameters have dominant influence) in the Humults of Windward Oahu would also be suited for dwellings and for the construction of local roads or streets. In some instances, however, soils that are not so well suited for these agricultural uses are better suited for these nonagricultural uses.

The soil potential ratings for the production of banana and sweet potato and for dwelling sites and for the construction of local roads or streets in the Humults of Windward Oahu are presented in Table 20. The approximate areas of each mapping unit and the Land-Capability classes and subclasses (Foote et al., 1972) are also presented in this table. In the rating system that was used in this study, in general, soils with good or fair potential for the selected agricultural uses also have similar ratings for the selected nonagricultural uses. Also, soils with good potential ratings for the different uses correspond to the Land-Capability Class II or III. Soils with 25 to 40% slopes have poor potential ratings for the different uses and correspond to the Land-Capability Class VI. Soils with slopes of more than 40% have poor potentials for different uses and correspond to the Land-Capability Class VII.

Soils with good or fair ratings for banana, based on non-controllable or overall parameters, have similar ratings for sweet potato. Banana can be grown on comparatively steeper slopes than sweet potato. Banana is also a longer duration crop requiring less tillage operations than sweet potato. On the other hand, a sandy loam texture is preferred for the sweet potato for the production of better-shaped tubers (deGuess, 1973; Kay, 1973). In addition, a soil pH of 5.5 to 6.5 is desirable for the prevention of certain diseases and for the optimum production of

Table 20. Potential Ratings of the Humults of Windward Oahu for Selected Uses

Soil Mapping Unit			Potential Ratings[1]						
Symbol	Name	Area (hectares)	Banana Non-con.	Banana Over-all	Sweet Potato Non-con.	Sweet Potato Over-all	Dwelling	Roads or Streets	SCS Capability Classification[2]
AeE	Alaeloa silty clay, 15-35 percent slopes	620	F	F	F	F	F	F	VIe
ALF	Alaeloa silty clay, 40-70 percent slopes	1116	P	P	P	P	P	P	VIIe
LoB	Lolekaa silty clay, 3- 8 percent slopes	878	G	G	G	G	G	G	IIe
LoC	Lolekaa silty clay, 8-15 percent slopes	187	G	F	F	F	G	F	IIIe
LoD	Lolekaa silty clay, 15-25 percent slopes	368	F	F	F	F	F	P	IVe
LoE	Lolekaa silty clay, 25-40 percent slopes	703	F	P	P	P	P	P	VIe
LoF	Lolekaa silty clay, 40-70 percent slopes	688	P	P	P	P	P	P	VIIe
PeB	Paumalu silty clay, 3- 8 percent slopes	140	G	G	G	G	G	G	IIe
PeC	Paumalu silty clay, 8-15 percent slopes	194	F	G	F	F	G	G	IIIe
PeD	Paumalu silty clay, 15-25 percent slopes	257	F	F	F	P	F	F	IVe
PeE	Paumalu silty clay, 25-40 percent slopes	221	P	P	P	P	F	P	VIe
PeF	Paumalu silty clay, 40-70 percent slopes	255	P	P	P	P	P	P	VIIe
WpB	Waikane silty clay, 3- 8 percent slopes	243	G	G	G	G	G	G	IIe
WpC	Waikane silty clay, 8-15 percent slopes	100	G	F	F	F	G	F	IIIe
WpE	Waikane silty clay, 25-40 percent slopes	1610	F	P	P	P	P	P	VIe
WpF	Waikane silty clay, 40-70 percent slopes	2325	P	P	P	P	P	P	VIIe
WpF2	Waikane silty clay, 40-70 percent slopes	331	P	P	P	P	P	P	VIIe
WpaE	Waikane stony silty clay, 15-30 percent slopes	125	F	P	F	P	P	P	VIIe

[1]Potential Ratings: G = Good, F = Fair, P = Poor.

[2]After Foote et al. (1972).

sweet potato (Kay, 1973).

The differences in morphological features such as color, grade of structure, and thickness of clay films are used in differentiating the soil series Alaeloa, Lolekaa, Paumalu, and Waikane (Appendix A; Foote et al., 1972). Surface horizons of these soils have good physical properties and nearly favorable chemical properties that are useful for the production of shallow or medium -rooted crops. The properties of the surface horizons have a great influence in the production of crops (Sopher and McCracken, 1973). The subsoils have high amounts of extractable Al (Figs. 13 through 16) and it is difficult to eliminate this particular element. Deep-rooted plants with low tolerance may perform poorly on these soils. Hence, the exposure of subsurface horizons by erosion or leveling should be minimized. In general, all of the four soil series have similar potentials for the different uses. The morphological features used to distinguish these soils or the physical or chemical properties associated with these soils do not differ significantly in influencing the different uses.

Within each soil series, the texture of the A horizon that is used to denote the soil type and the slopes, eroded phases, or stoniness that are used to distinguish soil phases affect soil potential ratings. The Alaeloa series, for example, has slopes greater than 15% and has fair to poor potential for the selected uses (Table 20). Similarly, in other soils, slope has a great influence in determining the potential ratings. In the Waikane soil, mapping units with eroded phase and steep slopes have poor potential for the selected uses. Similarly, the Waikane stony silty clay, 15 to 30% slopes, may have sufficient stone and may interfere with tillage operations and may produce odd-shaped sweet potato tubers. Soils of this mapping unit have a fair potential for agriculture based on noncontrollable parameters and poor rating based on overall rating.

The approximate areas of Humults with good, fair, and poor soil potential ratings are presented in Table 21. Of the more than 10,000 hectares of Humults in Windward Oahu, less than 1,500 and 1,750 hectares are rated good for agricultural and nonagricultural uses, respectively. Approximately an equal area, less than 1,550 hectares, are rated fair. On the other hand, approximately 7,000 to 7,750 hectares are rated poor for the selected uses.

It would be interesting to compare the above results with the actual use of the Humults in Windward Oahu. Perhaps a study of the recently obtained high altitude U-2 flight aerial photographs which are available at the State of Hawaii Department of Planning and Economic Development may be most useful.

Areas of Further Research

The study of the Humults of Windward Oahu showed varying

Table 21. Potential Ratings of the Humults of Windward Oahu and Their Approximate Areas

Uses	Category of Ratings	Potential Ratings		
		Good	Fair	Poor
		----- hectares -----		
Agricultural				
Banana	Noncontrollable	1,548	3,877	4,936
	Overall	1,455	1,532	7,374
Sweet potato	Noncontrollable	1,261	1,851	7,249
	Overall	1,261	1,469	7,631
Nonagricultural				
Dwellings	Overall	1,742	1,466	7,153
Local roads or streets	Overall	1,455	1,164	7,742

range in the characteristics. As demand for alternative land uses takes place, these soils should be mapped in greater detail so that refinement of the soil and landscape parameters as well as the classification at the lower categories can be attained.

As more demand for specific land use takes place, there is also a need to refine the method of calculating soil potentials for specific uses. When the parameters and their criteria and ratings are better identified, models other than the additive type should be utilized to calculate these soil potentials. Refinement of the soil potentials also means that there should be a systematic compilation of yield data of different crops in Hawaii.

As soil potentials of different soils become available, there should be a rapid display system of soil interpretive maps which are easily accessible so that the land users, the land planners, and others can utilize these maps. Examples of computerized soil interpretive maps are discussed by Nichols and Bartelli (1972) and by Nichols (1975).

SUMMARY AND CONCLUSIONS

The Ultisols dominate the sloping eroded landscape of Windward Oahu, Hawaii. Most of these soils are highly leached and contain appreciable amounts of extractable aluminum which influences plant growth. Because of the high amounts of organic carbon in the upper portion of the Bt or argillic horizon, these soils are further classified as Humults. The four important soil series are the Waikane, Lolekaa, Alaeloa, and Paumalu soils which occupy 4,700, 2,800, 1,700, and 1,000 hectares, respectively. They occur in areas with an annual rainfall ranging from 900 to 2,300 mm and with an isohyperthermic temperature regime.

The objectives of this investigation were (1) to determine and classify the soil and landscape parameters for selected agricultural and nonagricultural uses, (2) to characterize and verify the classification of the soils of the study area, (3) to show the geomorphic relationships of the Ultisols with the other soils, (4) to rate the soils for selected agricultural and nonagricultural uses, and (5) to identify the areas of further research required for efficient interpretation of soil and landscape data for different uses.

Pedons or profiles of Ultisols (Humults) were collected and laboratory data were obtained to determine the range in the characteristics of the chemical, physical, and mineralogical properties. In addition to the problems of soil acidity and soil aluminum, these soils have low inherent fertility and a high capacity to adsorb phosphorus. On the other hand, in general, they have fairly good physical characteristics for crop production. The soils are very strongly acidic to strongly acidic, with the pH values ranging from 4.5 to 5.4. The cation exchange capacity, by the sum of cations, ranges from 13 to 25 meq/100 g of soil, while the base saturation of the surface horizons ranges from 22 to 45%. This base saturation decreases with depth. Because the subsoils have high proportion of extractable aluminum (as much as 12 meq/100 g) and consequently high aluminum saturation (as much as 88%), crop production on these soils is limited to plants that can tolerate appreciable amounts of soil aluminum or crop production can be maintained only with proper management. Survey of literature cites many crops which have varying degree of tolerance to soil aluminum. Banana and sweet potato are two crops which can tolerate such a condition.

Additional chemical, physical, and mineral properties were determined to verify the classification of the Humults. Although only a limited number of morphologically similar pedons were collected, the laboratory data suggest a need to study further the Humults of Windward Oahu. It is highly likely that some of the Humults may need to be reclassified at the lower categories. In general, the Humults of Windward Oahu are Tropohumults with some of them tending to have properties of Palehumults.

They all are of clayey family, generally with varying mineralogy.

In general, the Humults of Leeward Oahu occur on a sloping landscape in association with Oxisols on a lower stable and nearly level to level landscape and with some other soils in the higher very steep landscape which includes the rough mountain lands. The Humults of Windward Oahu also occur on a sloping landscape but, except in localized areas, they do not occur in association with the Oxisols. Associations with Inceptisols, Entisols, Mollisols, and Vertisols appear to be the rule. Exposure of Windward Oahu to the Northeast Tradewinds and the subsequent effects of erosion is attributed to the occurrence of the existing landscape and soil associations and distribution.

One of the objectives of this investigation has been to rate the soils of Windward Oahu for selected agricultural and nonagricultural uses. Consequently, a system of determining the soil potentials for these uses has been proposed. Potential ratings for the production of banana and sweet potato were used to illustrate the system for agricultural uses and ratings for dwellings and for construction of local roads or streets were used to illustrate the system for nonagricultural uses. Certain soil and landscape parameters which cannot be altered easily by man (noncontrollable parameters) have strong influence or weightings than other parameters which can be altered by man (controllable parameters). Various criteria pertinent to the specific uses were rated and evaluated. The results of the ratings suggest that much of the Humults, especially those with steeper slopes, have poor or fair ratings for the production of banana and sweet potato in Windward Oahu. Humults with less steep slopes, however, have better ratings. The latter soils are limited in extent. The predominance of Humults with poor and fair ratings are to be expected because these soils (the Ultisols) are by definition highly leached soils with low inherent fertility and occur on sloping landscapes. The value of the potential rating system appears to be then in deciding which areas of Humults should be considered as "first" choice for a specific use.

Similar results of the ratings for dwellings and local roads or streets suggest that Humults in areas of steeper slopes have poor or fair ratings while those of less steep slopes have better ratings. These findings suggest further that in general soils that are good or fair for banana and sweet potato are also good or fair for dwellings and local roads or streets.

Although the final decision to use a particular site for a specific use will depend on other factors, such as socio-economic conditions, the concept of soil potentials can be used as the initial step in guiding the land users, land planners, and others in evaluating a soil, a parcel of land, or an area for a specific use.

Areas of further research include the systematic compilation of yield data of specific crops and refinement of the soil potential rating system. There is also a need to display the potential ratings especially by means of a computerized display system. Several systems are in existence but they should easily be accessible and up-dated and be subject to modification so that the information may be useful not only for general planning, but also for specific planning.

Based on the results of this investigation, the following conclusions are made:

1. The Humults of Windward Oahu, Hawaii, have varying ranges in the characteristics of physical, chemical, and mineralogical properties. Based on these properties, the Humults of Windward Oahu are not only Orthoxic or Humoxic Tropohumults, as presently classified, but also Typic Tropohumults and Typic Palehumults. Further study is necessary to confirm the classification of these soils.

2. The Humults of Windward Oahu occupy an unique place in the landscape. Although these soils possess low inherent fertility, they can still be used for agriculture if crops suited for such soils are selected and managed properly.

3. Using the soil survey and soil classification data, a proposed system of rating soils for a specific use can be used to evaluate the potential. This rating is based on the inherent parameters or properties and does not take into consideration economic factors, such as developmental cost, fertilizer cost,

nearness to market, etc.

4. Landscape parameters (noncontrollable parameters) such as slope have strong influence or weighting in rating soils. Soil parameters (controllable parameters) such as pH, on the other hand, have less influence or weighting in rating soils.

5. The major limiting factor for the production of banana and sweet potato in the Humults of Windward Oahu is steep slope.

6. The Humults of Windward Oahu that are suited for the production of banana and sweet potato are also suited for dwellings and for the construction of local roads or streets.

7. Based on the proposed method of rating soils, of the more than 10,000 hectares of Humults in Windward Oahu, less than 1,500 and 1,750 hectares are rated good for agricultural and nonagricultural uses, respectively. Approximately an equal area, less than 1,550 hectares, are rated fair. On the other hand, approximately 7,000 to 7,750 hectares are rated poor for the selected uses.

APPENDIX A

Profile Descriptions of Eight Soils of Windward Oahu

Alaeloa Clay
(Site A1--Koolau Boys' Home)

Location: Island of Oahu. Map sheet No. 65, Soil Survey of Island of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is pasture just SW of Koolau Boys' Home; 1 km SSE of Kailua High School; and approximately 0.6 km ESE of Maunawili School.

Date of sampling: March 15, 1974.

Described and collected by: H. Ikawa and A. R. Southard.

Remarks: Textures are apparent field textures. Colors are for moist soil unless otherwise noted.

A1 0 - 18 cm -- Dark yellowish brown (10YR 3/4) clay; moderate fine subangular blocky structure; hard, firm, sticky, plastic; many roots; clear wavy boundary.

B21 18 - 30 cm -- Dark reddish brown (2.5YR 3/4) and dark yellowish brown (10YR 3/4) clay; moderate very fine subangular blocky structure; hard, firm, sticky, plastic; many roots; very few thin clay films on peds and in pores; gradual boundary.

B22t 30 - 52 cm -- Dark red (10R 3/6) clay; moderate very fine and fine subangular blocky and moderate fine granular structure; slightly hard, friable, sticky, plastic; many roots; continuous thin clay films on peds; gradual boundary.

B23t 52 - 85 cm -- Dark red (10R 3/6) clay; moderate fine subangular blocky and granular structure; slightly hard, friable, sticky, plastic; many roots; continuous thick clay films on peds; gradual boundary.

B24t 85 - 115 cm -- Dark red (10R 3/6) clay; moderate fine subangular blocky and granular structure; slightly hard, friable, sticky, plastic; continuous thick clay films on peds; few roots; gradual boundary.

B25t 115 - 135 cm -- Dark red (10R 3/6) clay; dark red (2.5YR 3/6) on ped faces; moderate fine and medium subangular blocky structure; slightly hard, friable, sticky, plastic; continuous thick clay films on peds; few roots; gradual boundary.

B26t 135 - 150 cm -- Dark red (2.5YR 3/6) and olive gray (5YR 4/2) clay; moderate fine and medium subangular blocky and moderate fine granular structure; hard, firm, sticky, plastic; many thick clay films on peds; gradual boundary.

B27 150 - 170 cm -- A varigated mixture of dark red (2.5YR 3/6) reddish gray (5YR 5/6) olive (5Y 5/1) light gray (7.5YR 7/8) clay; structure, consistence, clay films same as above.

Alaeloa Silty Clay
(Site A2--Kapaa Quarry)

Location: Island of Oahu. Map sheet No. 65, Soil Survey of Island of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is south slope of Kapaa quarry which is located just west of Kawainui swamp in Kailua.

Date of sampling: March 4, 1974.

Described and collected by: H. Ikawa and A. R. Southard.

Remarks: Textures are apparent field textures. Colors are for moist soil.

A1 0 - 14 cm -- Dark reddish brown (5YR 3/3) silty clay; strong fine subangular blocky and moderate fine granular structure; hard, friable, sticky, plastic; many roots; clear, wavy boundary.

A12	14 - 24 cm	-- Dark reddish brown (2.5 YR 3/4) silty clay; fine and medium subangular blocky structure; hard, friable, sticky, plastic; many roots; abrupt, wavy boundary.
B21t	24 - 40 cm	-- Dark reddish brown (2.5YR 3/4) silty clay; moderate medium subangular blocky structure; slightly hard, firm, sticky, plastic; many roots; few thin clay films on peds; clear, wavy boundary.
B22t	40 - 75 cm	-- Weak red (10R 4/4) silty clay; moderate medium subangular blocky structure; hard, friable, sticky, plastic; many roots; continuous thick clay films on peds and in pores; gradual boundary.
B23t	75 - 103 cm	-- Weak red (10R 4/4) silty clay; strong fine subangular blocky structure; hard, friable, sticky, plastic; few fine roots; continuous thick clay films on peds and root pores; gradual boundary.
B24t	103 - 135 cm	-- Weak red (10R 4/4) silty clay; strong fine subangular blocky structure; hard, friable, sticky, plastic; continuous thick clay films on peds and in root pores; gradual boundary.
C1	135 - 150 cm	-- Weak red (2.5YR 4/2) and gray (7YR 5/8) saprolytes.

Lolekaa Clay
(Site L1--Kaneohe)

Location: Island of Oahu. Map sheet No. 60, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is in banana field on the west side of Likelike Highway, approximately 0.1 km SW of the intersection of Likelike and Kahekili Highways.

Date of sampling: April 1, 1974.

Described and collected by: H. Ikawa and A. R. Southard.

Remarks: Textures are apparent field textures. Colors are for moist soil.

Ap1	0 - 16	cm -- Very dark reddish brown (10YR 3/2) clay, strong fine subangular blocky structure; hard, firm,. sticky, plastic; many roots; abrupt wavy boundary.
B21	16 - 36	cm -- Very dark greyish brown (10YR 3/2) clay, moderate very fine and fine subangular blocky structure; hard, firm, sticky, plastic; many roots; clear, wavy boundary.
B22t	36 - 63	cm -- Dark grayish brown (10YR 4/2) clay; moderate very fine and subangular blocky structure; firm, sticky, plastic; few roots; approximately 5 percent of weathered gravels (2-4 cm in diameter) with fine pores, low bulk density; krotoviana of 9 cm in diameter filled with dark grayish brown material occupying part of the horizon; diffuse boundary.
B23t	63 - 99	cm -- Dark grayish brown (10YR 4/2) clay; moderate very fine and fine subangular blocky structure; hard, firm, sticky, plastic; few roots; thin clay films on peds and on gravels; less than 5 percent gravel by volume; gradual boundary.
B24t	99 - 130	cm -- Dark grayish brown (10YR 4/2) clay; moderate very fine and fine subangular blocky structure; hard, firm, sticky, plastic, few roots; very few thin clay films on peds and weathered gravels; less than 5 percent gravel by volume; abrupt, wavy boundary.
B25t	130 - 160	cm -- Dark grayish brown (10YR 4/2) and dark yellowish brown (10YR 4/4) gravelly clay; moderate very fine subangular blocky structure; firm, sticky, plastic; few roots; very few thin clay films on peds and gravels; gradual boundary.
B26t	160 - 190	cm -- Dark grayish brown (10YR 4/2) and dark yellowish brown (10YR 4/4) gravelly clay; moderate very fine and fine subangular blocky structure; firm, sticky, plastic; few roots; very few thin clay films on peds and gravels; gravels can be broken in the hand with difficulty.

Lolekaa Clay
(Site L2--Haiku)

Location: Island of Oahu. Map sheet No. 60, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is in military reservation approximately 0.1 km west of the headquarters building.

Date of sampling: April 16, 1974.

Described and collected by: S. P. Periaswamy, H. Ikawa, and A. R. Southard.

Remarks: Textures are apparent field textures. Colors for moist soil.

A11	0 - 4 cm	-- Dark brown (10YR 3/3); strong fine subangular blocky structure; very hard, very firm, sticky, plastic; many roots; gradual boundary.
A12	4 - 23 cm	-- Dark yellowish brown (10YR 4/4) clay; strong fine subangular blocky structure; very firm, sticky, plastic; few roots; gradual boundary.
B21	23 - 62 cm	-- Dark yellowish brown (10YR 4/4) clay; moderate very fine and very fine subangular blocky structure; firm, sticky, plastic; few roots; gradual boundary.
B22	62 - 94 cm	-- Dark yellowish brown (10YR 3.5/4) clay; moderate very fine and fine subangular blocky structure; hard, firm, sticky, plastic; few roots; few gravels of 1 - 2 cm diameter; gradual boundary.
B23	94 - 125 cm	-- Dark yellowish (10YR 3.5/4) clay; weak fine subangular blocky and granular structure; hard, firm, sticky, plastic; few roots; gradual boundary.
B24	125 - 160 cm	-- Dark yellowish brown (10YR 3/4) clay; weak fine subangular blocky structure; hard, firm, sticky, plastic; no roots; gradual boundary.

B25 160 - 190 cm -- Dark yellowish brown (10YR 3/4) clay; weak fine subangular blocky and granular structure; hard, firm, slightly sticky, plastic; no roots; few dark gray (5YR 4/6) weathered gravels up to 10 cm thickness.

Paumalu Clay
(Site P1--Puu Kauweweole)

Location: Island of Oahu. Map sheet No. 47, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is in military training area, approximately 2 km SSW of Waialee.

Date of sampling: April 29, 1974.

Described and collected by: H. Ikawa and A. R. Southard.

Remarks: Textures are apparent textures. Colors are for moist soil.

A1 0 - 24 cm -- Dark reddish brown (2.5YR 3/4) clay; strong fine and very fine subangular blocky structure; extremely hard, firm, sticky, plastic; many roots; clear wavy boundary.

B21t 24 - 52 cm -- Dark reddish brown (2.5YR 3/4) clay; strong fine subangular blocky structure; extremely hard, firm, sticky, plastic; many roots; many thick dark reddish brown (5YR 3/4) clay films on peds; clear wavy boundary.

B22t 52 - 78 cm -- Dark reddish brown (2.5YR 3/4) clay; moderate fine subangular blocky structure; extremely hard, firm, sticky, plastic; few roots; continuous thick clay films on peds; diffuse boundary.

B23t 78 - 117 cm -- Dark reddish brown (5YR 3/3) clay; moderate fine subangular blocky structure; extremely hard, firm, sticky, plastic; few roots; continuous thick clay films on peds; gradual boundary.

B24t 117 - 155 cm -- Dark reddish brown (5YR 3/4) clay; moderate very fine and fine subangular blocky structure; extremely hard, firm, sticky, plastic; few roots; continuous thick dark red (2.5YR 3/6) clay skins on peds; few roots; gradual boundary.

B25t 155 - 190 cm -- Dark reddish brown (5YR 3/4) clay; moderate very fine and fine subangular blocky structure; extremely hard; firm, sticky, plastic; few roots; continuous thick dark red (2.5YR 3/6) clay skins on peds; few roots.

Paumalu Clay
(Site P2--Laie)

Location: Island of Oahu. Map sheet No. 48, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is south of passion fruit orchard, approximately 3 km west of Laie.

Date of sampling: April 17, 1974.

Described and collected by: H. Ikawa, A. R. Southard, and R. C. Bowden.

Remarks: Textures are apparent textures. Colors are for moist soil.

A11 0 - 18 cm -- Dark reddish brown (5YR 3/2) clay; strong very fine subangular blocky and moderate fine granular structure; firm, sticky, plastic; many roots; diffuse boundary.

A12 18 - 41 cm -- Dark reddish brown (5YR 3/2) clay; strong very fine subangular and fine granular structure; firm, sticky, plastic; few roots; clear smooth boundary.

B21t 41 - 72 cm -- Reddish brown (5YR 4/4) clay; strong, very fine and fine subangular blocky structure; very firm, sticky, plastic; few roots; many thick clay films on peds; diffuse boundary.

B22t 72 - 100 cm -- Reddish brown (5YR 4/4) clay; strong very fine and fine subangular blocky structure; very firm, sticky, plastic; few roots; many thick clay films on peds; gradual boundary.

B23t 100 - 120 cm -- Dark reddish brown (5YR 3/3) clay; moderate very fine and fine subangular blocky structure; very firm, sticky, plastic; few roots; many thick clay films on peds; weathered gravels of 2 - 4 cm make up about 10% of this horizon.

B24t 120 - 140 cm -- Dark reddish brown (5YR 3/4) clay; moderate very fine and fine subangular blocky structure; firm, sticky, plastic; few roots; many thick clay films on peds; weathered gravels of 2 - 3 cm thickness make up about 10% by volume.

C1 140 - 150 cm -- Saprolyte of varigated red and yellow colors.

Waikane Clay
(Site W1--Kaaawa)

Location: Island of Oahu. Map sheet No. 57, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is in pasture in valley located approximately 1.2 km NW of Waikane.

Date of sampling: March 28, 1974.

Described and collected by: A. R. Southard, S. P. Periaswamy, H. Ikawa, and R. C. Bowden.

Remarks: Textures are apparent textures. Colors are for moist soil.

Ap1 0 - 15 cm -- Dark reddish brown (5YR 3/4) clay; strong fine subangular blocky structure; hard, firm, sticky, plastic; many roots; some mixing by burrowing animals; clear wavy boundary.

B21 15 - 35 cm -- Reddish brown (5YR 4/4) clay; moderate medium subangular blocky structure; hard,

		firm, sticky, plastic; many roots; common, moderately thick, clay films on peds and in pores; gradual boundary.
B22t	35 - 60	cm -- Reddish brown (5YR 4/4) clay; moderate medium subangular blocky structure; hard, firm, sticky; common moderate thick clay films on the faces of weathered gravels; gradual wavy boundary.
B23t	60 - 85	cm -- Reddish brown (5YR 4/4) clay; moderate medium subangular blocky structure; firm, sticky, plastic; common moderately thick clay films on peds, in pores and many thick clay films on the faces of weathered gravels; gradual boundary.
B24t	85 - 115	cm -- Reddish brown (5YR 4/4), yellowish red (5YR 4/8) and dark gray (5YR 4/1) clay; moderate medium subangular blocky structure; firm, sticky, plastic; many thick clay films on peds, in pores and on weathered gravels; gradual boundary.
B25t	115 - 140	cm -- Reddish brown (5YR 4/4), yellowish red (5YR 4/8), and dark gray (5YR 4/1) clay; moderately medium subangular blocky structure; firm, sticky, plastic; many thick clay films on peds, in pores and on faces of weathered gravels; evidence of precipitated iron oxide in vesicles of weathered gravels; gradual boundary.
B26	140 - 160	cm -- Reddish brown (5YR 4/4), yellowish red (5YR 4/8), and dark gray (5YR 4/1) clay; moderate medium subangular blocky structure; firm, sticky, plastic; common, moderately thick clay films on peds, in pores and on faces of weathered gravels; evidence of precipitated iron oxides in the vesicles of weathered gravels; gradual boundary.
B27	160 - 190	cm -- Reddish brown (5YR 4/4), yellowish red (5YR 4/8), and dark gray (5YR 4/1) clay; moderate medium subangular blocky structure; firm, sticky, plastic; many thick clay films on peds, in pores and on faces of weathered gravels.

Waikane Clay Loam
(Site W2--Waiahole)

Location: Island of Oahu. Map sheet No. 58, Soil Survey of Islands of Kauai, Oahu, Maui, Molokai, and Lanai, State of Hawaii (Foote et al., 1972). Sample site is recently cultivated field next to road, approximately 1.6 km west of Waiahole School.

Date of sampling: March 21, 1974.

Described and collected by: S. P. Periaswamy, A. R. Southard, H. Ikawa, and R. C. Bowden.

Remarks: Textures are apparent textures. Colors are for moist soil.

Ap1	0 - 16 cm	-- Dark yellowish brown (10YR 3/4) clay loam; strong medium granular structure; firm, sticky, plastic; many roots; gradual boundary.
B21	16 - 28 cm	-- Dark brown (7.5YR 3/2) clay; moderate fine granular structure; firm, sticky, plastic; many roots; common moderately thick clay films on peds and in pores; clear smooth boundary.
B22t	28 - 46 cm	-- Brown (7.5YR 4/4) clay; moderate very fine subangular blocky structure; firm, sticky, plastic; few roots; many moderately thick clay films on peds and in pores; clear wavy boundary.
B23t	46 - 74 cm	-- Very dark brown (7.5R 3/2) clay; moderate very fine and fine subangular blocky structure; firm, sticky, plastic; few roots; many thick clay films on peds and in pores; about five percent of weathered rocks of different color; clear wavy boundary.
B24t	74 - 99 cm	-- Dark brown (7.5YR 3/2) and brown (7.5YR 4/4) clay; moderate very fine and fine subangular blocky structure; firm, sticky, plastic; few roots; common moderately thick clay films on peds, in pores and on weathered gravels; 10 - 15% of volume occupied by

weathered gravels (1 - 5 cm thickness) of different colors; diffuse boundary.

B25t 99 - 142 cm -- Dark brown (7.5YR 3/2) and dark yellowish brown (10YR 4/4) clay; moderate very fine and fine subangular blocky structure; firm, sticky, plastic; few roots; common moderately thick clay films on peds, in pores and on weathered gravels; a few weathered rocks, 2 - 5 cm thickness (red, gray and brown).

C1 142 - 183 cm -- Auger sample; saprolytes of dark brown (7.5YR 3/2) yellowish brown (10YR 5/6) and yellowish red (5YR 4/6) clay.

APPENDIX B

Illustration of Calculation of Soil Potential for Banana Production for Soil Mapping LoB (Table 13)

1. In Table 13, observe that there are three noncontrollable and seven controllable parameters. The first noncontrollable parameter is slope in column 2. Soil mapping units are listed in column 1.

2. In Table 9, note that the slope of the soil mapping unit LoB ranges from 3 to 8 percent. Other parameters are also listed in this same table.

3. In Table 12, slopes ranging from 0 to 8 percent (LoB has 3 to 8 percent) are rated as 5 (low number is least favorable, while high number is most favorable). Because slope plays a dominant role, it is given a weighting of 6 (low number is least influence, while high number is most influence). The product of 6 x 5 or 30 is then entered in Table 13 under column 2. It should be noted from Table 12 that a product of 30 is also the highest score possible, as shown in the last row, column 2, of Table 13.

4. Similarly, the ratings of the other noncontrollable parameters, texture and mineralogy, can be determined by utilizing Tables 9 and 12, and the scores can be entered in Table 13 under columns 3 and 4. Thus, the sum of the scores of noncontrollable parameters for LoB is 48.

5. Assuming the noncontrollable parameters of LoB to be all "most favorable," then, the maximum sum of score possible would be (6 x 5) + (5 x 3) + (4 x 3) or 57 (see last row, columns 2 through 5, Table 13).

6. The actual sum of score of 48 can be expressed as percent by dividing 48 by 57 and multiplying by 100 which turns out to be 84 percent.

7. Using a three-class system of good, fair, and poor for the ranges 70 to 100, 50 to 69, and less than 50 percents, respectively, the mapping unit LoB, based on the noncontrollable parameters, is rated good for banana production.

8. The controllable parameters are next considered to determine the overall ratings, using Tables 10 and 13.

9. When all of the controllable parameters are rated the overall sum of scores (Table 13) can be obtained by adding 30 + 10 + 8 (noncontrollable parameters) + 12 + 4 + 2 + 4 + 2 + 2 + 2 (controllable parameters) which turns out to be 76. The maximum score possible, as shown in the last row again, is 30 + 15 + 12 (noncontrollable parameters) + 12 + 6 + 6 + 6 + 3 + 3 + 3 (controllable parameters) or 96.

10. An overall sum of scores of 76 is 79 percent (76/79 x 100 = 79 percent). According to the three-class system of good, fair, and poor for the ranges 75 to 100, 65 to 74, and less than 65 percents, respectively, the mapping unit LoB, based on both noncontrollable and controllable parameters, is rated good for banana production.

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